Attachment 6

To

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Revised Holtec Licensing Report for SFP Criticality Analysis (Non Proprietary)

HOLTEC INTERNATIONAL

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Licensing Report For Waterford Unit 3 Spent Fuel Pool Criticality Analysis

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☒ Technical Report (Per HQP 3.2) (Such as a Licensing Report)

☐ Design Criterion Document (Per HQP 3.4)

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Summary of Revisions:

Revision 0: Original Issue

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Shaded areas indicate where proprietary information has been removed.

1. INTRODUCTION

This report documents the criticality safety evaluation for the storage of Standard and Next Generation Fuel (NGF) assemblies in Holtec Region 1 & 2 style high-density spent fuel storage racks (SFSRs) at the Waterford Unit 3 nuclear power plant operated by Entergy Nuclear. The purpose of the present analysis is to re-perform the original criticality analysis, taking credit for soluble boron, in order to qualify the racks, etc. for the storage and handling of fuel assemblies having new fuel parameters.

Additional calculations are also documented such as the criticality analysis for storing fuel with an initial enrichment of up to 5.0 wt% ^{235}U in the Reactor Building Temporary Storage Rack (TSR) and storing fuel rods with an initial enrichment of up to 5.0 wt% ^{235}U in the Fuel Pin Storage Container (FPSC) in the spent fuel pool, a boron dilution analysis of the spent fuel pool, a criticality analysis of additional spent fuel pool equipment and also the New Fuel Storage Vault (NFV) (See Section 5.6).

The results of the Region 1 calculations are summarized in Table 7.1 through Table 7.6. The calculations demonstrate that maximum k_{eff} is less than 1.0 without credit for soluble boron and less than or equal to 0.95 with 85 ppm soluble boron. Furthermore, all reactivity effects of abnormal and accident conditions have also been evaluated to assure that under all credible abnormal and accident conditions, the reactivity will not exceed the regulatory limit of 0.95 with 193 ppm soluble boron present.

The results of the Region 2 calculations are summarized in Table 7.7 through Table 7.22, and Table 7.26 through Table 7.27, and Table 7.29. Under normal conditions, a soluble boron concentration of 524 ppm is required in the spent fuel pool. Under credible accident conditions, a soluble boron concentration of 870 ppm is required (see Table 7.21).

Three loading patterns have been qualified for the Region 2 racks (See Tables 7.16 through Table 7.20):

- a uniform loading of spent fuel meeting the burnup versus enrichment requirements of Table 7.26,
- a checkerboard of high and low reactivity fuel (i.e., spent fuel checkerboard). The high reactivity fuel assembly must have an enrichment no greater than 5.0 wt% ^{235}U and a burnup greater than 27 GWD/MTU and the low reactivity fuel must meet the burnup versus enrichment requirements of Table 7.27,
- a checkerboard of fresh (or irradiated) fuel up to 5.0 wt% ^{235}U and empty cell locations (i.e., fresh fuel checkerboard).

Within Region 2 racks, several interfaces are possible with the three loading patterns qualified for storage. The permissible interface conditions are summarized as follows:

- No restrictions are necessary between the uniform loading pattern and either of the checkerboard loading patterns (fresh or spent).
- For interfaces between a fresh fuel checkerboard and spent fuel checkerboard, the high reactivity spent fuel assembly (5.0 wt% ^{235}U, 27 GWD/MTU) may be face adjacent to no more than one fresh (or irradiated) fuel assembly. The fresh (or irradiated) fuel assembly may be face adjacent with up to 2 high reactivity spent fuel assemblies. Figure 7.4 shows one example of an acceptable 3x3 fresh fuel checkerboard within the center of a spent fuel checkerboard that meets these requirements.

2. METHODOLOGY

2.1 Criticality Analysis

The principal method for the criticality analysis of the high-density storage racks is the use of the three-dimensional Monte Carlo code MCNP4a [2]. MCNP4a is a continuous energy three-dimensional Monte Carlo code developed at the Los Alamos National Laboratory. MCNP4a was selected because it has been used previously and verified for criticality analyses and has all of the necessary features for this analysis. MCNP4a calculations used continuous energy cross-section data predominantly based on ENDF/B-V and ENDF/B-VI. Exceptions are two lumped fission products calculated by the CASMO-4 depletion code, which do not have corresponding cross sections in MCNP4a. For these isotopes, the CASMO-4 cross sections are used in MCNP4a. This approach has been validated in [3] by showing that the cross sections result in the same reactivity effect in both CASMO-4 and MCNP4a.

Benchmark calculations, presented in Appendix A, indicate a bias of [redacted] with an uncertainty of ± [redacted] for MCNP4a, evaluated with a 95% probability at the 95% confidence level [1]. The calculations for this analysis utilize the same computer platform and cross-section libraries used for the benchmark calculations discussed in Appendix A.

The convergence of a Monte Carlo criticality problem is sensitive to the following parameters: (1) number of histories per cycle, (2) the number of cycles skipped before averaging, (3) the total number of cycles and (4) the initial source distribution. The MCNP4a criticality output contains a great deal of useful information that may be used to determine the acceptability of the problem convergence. This information has been used in parametric studies to develop appropriate values for the aforementioned criticality parameters to be used in storage rack criticality calculations. Based on these studies, a minimum of 10,000 histories were simulated per cycle, a minimum of 50 cycles were skipped before averaging, a minimum of 100 cycles were accumulated, and the initial source was usually specified as uniform over the fueled regions (assemblies). Further, the output was reviewed to ensure that each calculation achieved acceptable convergence. These parameters represent an acceptable compromise between calculational precision and computational time.

Fuel depletion analyses during core operation were performed with CASMO-4 (using the 70-group cross-section library), a two-dimensional multigroup transport theory code based on the Method of

Characteristics [4-6]. Detailed neutron energy spectra for each rod type are obtained in collision probability micro-group calculations for use in the condensation of the cross sections. CASMO-4 is used to determine the isotopic composition of the spent fuel. In addition, the CASMO-4 calculations are restarted in the storage rack geometry, yielding the two-dimensional infinite multiplication factor (k_{inf}) for the storage rack to determine the reactivity effect of fuel and rack tolerances, temperature variation, and to perform various studies. For all calculations in the spent fuel pool racks, the Xe-135 concentration in the fuel is conservatively set to zero.

Benchmark calculations, presented in [11], [redacted] for CASMO-4 evaluated with a 95% probability at the 95% confidence level [1]. [redacted]

The maximum k_{eff} is determined from the MCNP4a calculated k_{eff}, the calculational bias, the temperature bias, and the applicable uncertainties and tolerances (bias uncertainty, calculational uncertainty, rack tolerances, fuel tolerances, depletion uncertainty) using the following formula:

$$\text{Max } k_{eff} = \text{Calculated } k_{eff} + \text{biases} + [\textstyle\sum_i (\text{Uncertainty})^2]^{1/2}$$

In the geometric models used for the calculations, each fuel rod and its cladding were described explicitly, and reflecting or periodic boundary conditions were used in the radial direction which has the effect of creating an infinite radial array of storage cells, except for the assessment of certain accident conditions.

2.2 Boron Dilution Accident

The methodology related to the Boron Dilution accident follows the general equation for boron dilution which is,

$$C_t = C_o e^{-\frac{F}{V}t},$$

where

C_t = boron concentration at time t,
C_o = initial boron concentration,
V = volume of water in the pool, and
F = flow rate of un-borated water into the pool

This equation conservatively assumes the un-borated water flowing into the pool mixes instantaneously with the water in the pool.

For convenience, the above equation may be re-arranged to permit calculating the time required to dilute the soluble boron from its initial concentration to a specified minimum concentration, which is given below.

$$t = \frac{V}{F} \ln(C_o / C_t)$$

If V is expressed in gallons and F in gallons per minute (gpm), the time, t, will be in minutes.

3. ACCEPTANCE CRITERIA

The high-density spent fuel PWR storage racks for Waterford Unit 3 are designed in accordance with the applicable codes and standards listed below. The objective of this evaluation is to show that the effective neutron multiplication factor, k_{eff}, is less than 1.0 with the racks fully loaded with fuel of the highest anticipated reactivity, and flooded with un-borated water at a temperature corresponding to the highest reactivity. In addition, it is to be demonstrated that k_{eff} is less than or equal to 0.95 with the racks fully loaded with fuel of the highest anticipated reactivity, and flooded with borated water at a temperature corresponding to the highest reactivity. The maximum calculated reactivity includes a margin for uncertainty in reactivity calculations including manufacturing tolerances and is shown to be less than 0.95 with a 95% probability at a 95% confidence level [1]. Reactivity effects of abnormal and accident conditions have also been evaluated to assure that under all credible abnormal and accident conditions, the reactivity will not exceed the regulatory limit of 0.95 under borated conditions.

Applicable codes, standard, and regulations or pertinent sections thereof, include the following:

- Code of Federal Regulations, Title 10, Part 50, Appendix A, General Design Criterion 62, "Prevention of Criticality in Fuel Storage and Handling."
- USNRC Standard Review Plan, NUREG-0800, Section 9.1.1, Criticality Safety of Fresh and Spent Fuel Storage and Handling, Rev. 3 – March 2007.
- USNRC letter of April 14, 1978, to all Power Reactor Licensees - OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications (GL-78-011), including modification letter dated January 18, 1979 (GL-79-004).
- L. Kopp, "Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants," NRC Memorandum from L. Kopp to T. Collins, August 19, 1998.
- USNRC Regulatory Guide 1.13, Spent Fuel Storage Facility Design Basis, Rev. 2, March 2007.

- ANSI ANS-8.17-1984, Criticality Safety Criteria for the Handling, Storage and Transportation of LWR Fuel Outside Reactors.

- Code of Federal Regulations, Title 10, Part 50, Section 68, "Criticality Accident Requirements."

The New Fuel Storage Vault is intended for the receipt and storage of fresh fuel under normally dry conditions where the reactivity is very low. To assure criticality safety under accident conditions and to conform to the requirements of 10 CFR 50.68, these two accident condition criteria must be met:

- When fully loaded with fuel of the highest anticipated reactivity and flooded with clean unborated water, the maximum reactivity, including uncertainties, shall not exceed a k_{eff} of 0.95.

- With fuel of the highest anticipated reactivity in place and assuming the optimum hypothetical low density moderation, (i.e., fog or foam), the maximum reactivity shall not exceed a k_{eff} of 0.98.

These criteria preclude a secondary accident per ANSI 8.1 or accidents under dry conditions.

4. ASSUMPTIONS

To assure the true reactivity will always be less than the calculated reactivity, the following conservative design criteria and assumptions were employed:

1) Moderator is borated or un-borated water at a temperature in the operating range that results in the highest reactivity, as determined by the analysis.

2) Neutron absorption in minor structural members is neglected, i.e., spacer grids are replaced by water.

3) The effective multiplication factor of an infinite radial array of fuel assemblies was used in the analyses, except for the assessment of certain abnormal/accident conditions and conditions where leakage is inherent.

4) The neutron absorber length is modeled to be the same length as the active region of the fuel.

5) No cooling time is credited in the rack calculations.

6) The presence of burnable absorbers in fresh fuel is neglected. This is conservative as burnable absorbers would reduce the reactivity of the fresh fuel assembly.

7) The presence of annular pellets is neglected. This is conservative as it is bounded by the solid fuel.

8) All structural materials of the new fuel storage racks are conservatively neglected and replaced with water at the appropriate density.

9) The concrete wall of the transfer canal is conservatively modeled as 100 cm thick.

10) The FPSC tubes holes were not modeled; however, the other steel structures of the FPSC were modeled as water. Therefore, the neglecting of the tube holes is conservative.

11) The concrete walls of the vault are conservatively modeled as 100 cm thick.

12) The two inch redwood planks in the NFV are assumed to be 1.5 inches thick.

13) In MCNP4a, the Doppler treatment and cross-sections are valid at 300K (80.33 °F); however, in the NFV calculations no temperature bias is applied to the results to account for the actual temperature of the water.

14) In the NFV the eccentric fuel positioning condition is covered by the fuel cell spacing tolerance.

5. INPUT DATA

5.1 Fuel Assembly Specification

The spent fuel storage racks are designed to accommodate various 16x16 fuel assemblies used at the Waterford Unit 3 facility. The design specifications for these fuel assemblies, which were used for this analysis, are given in Table 5.1.

5.2 Core Operating Parameters

Core operating parameters are necessary for fuel depletion calculations performed with CASMO-4. The core parameters used for the depletion calculations are presented in Table 5.2. Temperature and soluble boron values are taken as the upper bound (most conservative) of the core operating parameters of Waterford Unit 3. The neutron spectrum is hardened by each of these parameters, leading to a greater production of plutonium during depletion, which results in conservative reactivity values.

5.3 Axial Burnup Distribution

Generic axial burnup profiles provided by the client are specified at node centers for 25 equally-spaced axial sections for burnups of less than 25 GWD/MTU and greater than 25 GWD/MTU. The resulting profiles are presented in Table 5.3.

5.4 Burnable Absorbers

At the Waterford Unit 3 facility there is the potential for either B_4C, erbia or IFBA burnable absorbers to be located in the fuel assembly as integral absorbers. In [10] it is clearly seen that the reactivity of the fuel assembly with IFBA bound those with B_4C or erbia and therefore only the IFBA is considered in this analysis. The design specifications for the IFBA rods are given in Table 5.1 and are further discussed in Section 7.2.2.

5.5 Storage Rack Specification

The storage cell characteristics are summarized in Table 5.4.

5.5.1 Region 1 Style Storage Racks

The Region 1 storage cells are composed of stainless steel boxes separated by a water gap, with fixed neutron absorber panels centered on each side. The steel walls define the storage cells, and stainless steel sheathing supports the neutron absorber panel and defines the boundary of the flux-trap water-gap used to augment reactivity control. Stainless steel channels connect the storage cells in a rigid structure and define the flux-trap between the neutron absorber panels. Neutron absorber panels are installed on all exterior walls facing other racks.

The calculational models consist of a single cell with reflective boundary conditions through the centerline of the water gaps, thus simulating an infinite array of Region 1 storage cells. Figure 5.1 shows the actual calculational model containing the reference 16x16 assembly, as drawn by the two-dimensional plotter in MCNP4a. The calculations are described in Section 7.1.

5.5.2 Region 2 Style Storage Racks

The Region 2 storage cells are composed of stainless steel boxes with a single fixed neutron absorber panel, (attached by stainless steel sheathing) centered on each side. The stainless steel boxes are arranged in an alternating pattern such that the connection of the box corners form storage cells between those of the stainless steel boxes.

The calculational models consist of a group of four identical cells surrounded by reflective boundary conditions through the centerline of the composite of materials between the cells, thus simulating an infinite array of Region 2 storage cells. Figure 5.2 shows the actual calculational model containing the 16x16 assembly as drawn by the two-dimensional plotter in MCNP4a. The calculations are described in Section 7.2.

5.5.3 Rack Interfaces

Based on the layout of the spent fuel pool, there are no Region 1 to Region 2 interfaces. The gap between adjacent Region 2 racks is conservatively neglected. The Region 2 to Region 2 rack loading pattern interfaces are analyzed in Section 7.3.

5.6 Additional Calculations

5.6.1 Fuel Transfer Carriage Criticality

The fuel transfer carriage conveys the fuel assemblies through the fuel transfer tube and is capable of accommodating two fuel assemblies at a time, carried in stainless steel boxes. The results of this calculation can be found in Section 7.4.1.

5.6.2 Upender Criticality

The fuel upender is a machine located at each end of the transfer tube. The criticality of this component is bounded by the fuel transfer carriage. No input required. See Section 7.4.2.

5.6.3 New Fuel Elevator Criticality

The new fuel elevator has a capacity of a single fuel assembly and is utilized to lower new fuel from the operating level of the fuel handling building to the bottom of the spent fuel pool. See Section 7.4.3.

5.6.4 Boron Dilution Accident Evaluation

The spent fuel pool at Waterford Unit 3 was conservatively assumed to have a soluble boron concentration of 1720 ppm. The spent fuel pool volume is considered to be 38,600 ft^3. Under certain abnormal conditions, un-borated water may dilute this concentration below the requirements determined in Section 7.

Makeup to the spent fuel storage pool is from the Refueling Water Storage Pool and/or the Condensate Storage Pool. Makeup from the Refueling Water Storage Pool is provided by the refueling water pool purification pump which has a capacity of 150 gpm. The Refueling Water Storage Pool has a minimum boron concentration of 2050 ppm. The component cooling water makeup pumps provide makeup from the Condensate Storage Pool and have a capacity of 600 gpm. For the accident case a high flow rate of 600 gpm is therefore assumed. The results of these calculations are shown in Section 7.4.4.

5.6.5 Temporary Storage Racks

The TSR storage cell locations are arranged in a row of 5 cells with the geometric dimensions in Table 5.5. The design basis calculational model places 5 fresh fuel assemblies enriched to 5.0 wt% ^{235}U in the storage rack. No steel structural material is included. For simplification, the following tolerances are included in the design basis model: fuel density, lattice pitch and enrichment.

5.6.6 Fuel Pin Storage Container

The FPSC is a square stainless steel container that fits in a fuel assembly storage rack in the spent fuel pool. It has 81 stainless steel tubes that may contain fuel rods of up to 5.0 wt% ^{235}U (See Table 5.5). The FPSC was modeled as 81 solid steel tubes of equal diameter, each containing 1 fresh fuel rod with the maximum enrichment. All other steel components of the container were neglected. The model includes 100 cm of water surrounding the FPSC or fuel assembly.

The criticality analysis of the FPSC is performed by comparing the reactivity of the FPSC loaded with the maximum number of fresh fuel pins to the reactivity of various fuel assemblies and determine which cases bound the FPSC. These calculations are performed with the fuel assembly surrounded by 100 cm of water, meaning no storage racks, poison material or structural materials are considered (the steel tubes of the FPSC are modeled). No tolerances are included. Reflective boundary conditions are applied on all sides to maximize reactivity.

5.6.7 New Fuel Storage Vault

The NGF assembly is the only fuel assembly type to be stored in the NFV. The design input data is tabulated in Table 5.1 and Table 5.6. The storage locations are arranged in 8 modules providing a total of 16 rows of 5 cells each for a total of 80 storage locations. The cells are located on a 21 inch pitch within each module, and on a 49 inch cell center to cell center spacing between modules in the east-west direction and a 58 inch cell center to cell center spacing between modules in the north-south direction. Normally, fuel is stored in the dry condition with very low reactivity. Graphic representations of the analytical model are shown in Figure 7.5 and 7.6. These figures were drawn (to scale) with a two-dimensional plotter.

The reactivity uncertainties associated with various manufacturing tolerances for the NFV were calculated by the difference between two MCNP4a calculations, one with the nominal value and a second independent calculation with the tolerance parameter changed. Based on the nominal condition results, it was determined that the 100% moderator condition, i.e. 1.0 g/cc, represented the maximum reactivity condition and therefore the tolerance calculations were performed with 100% moderator density. These tolerance effects each include the combination of statistical errors in the MCNP4a calculations due to the random nature of Monte Carlo calculations, at the 95% confidence level ($\Delta k+(\sqrt{2})*2*\sigma$). In evaluating the uncertainties due to tolerances, the following tolerances were used:

- Enrichment Tolerance of ± 0.05 wt% ^{235}U
- Density of ±0.165 g UO_2/cm^3

- Fuel Storage Cell Spacing of [redacted]

The fuel storage cell spacing tolerance was only used in the 21 inch assembly pitch. In determining the maximum k_{eff}, the effects of these manufacturing tolerances were statistically combined (square root of the sum of the squares) with the MCNP4a bias uncertainty from the benchmarking results and the MCNP4a calculational statistics ($2*\sigma$) to determine the total uncertainty.

6. COMPUTER CODES

The following computer codes were used during this analysis.

- MCNP4a [2] is a three-dimensional continuous energy Monte Carlo code developed at Los Alamos National Laboratory. This code offers the capability of performing full three-dimensional calculations for the loaded storage racks. MCNP4a was run on the PCs at Holtec.

- CASMO-4, Version 2.05.14 [4-6] is a two-dimensional multigroup transport theory code developed by Studsvik Scandpower, Inc. CASMO-4 performs cell criticality calculations and burnup. CASMO-4 has the capability of analytically restarting burned fuel assemblies in the rack configuration. This code was used to determine the reactivity effects of tolerances and fuel depletion.

7. ANALYSIS

This section describes the calculations that were used to determine the acceptable storage criteria for the Region 1 and Region 2 style racks. In addition, this section discusses the possible abnormal and accident conditions.

Unless otherwise stated, all calculations assumed nominal characteristics for the fuel and the fuel storage cells. The effect of the manufacturing tolerances is accounted for with a reactivity adjustment as discussed below.

As discussed in Section 2, MCNP4a was the primary code used in the PWR calculations. CASMO-4 was used to determine the reactivity effect of tolerances and for depletion calculations. MCNP4a was used for reference cases and to perform calculations which are not possible with CASMO-4 (e.g., eccentric fuel positioning, axial burnup distributions, and fuel misloading).

Figures 5.1 and 5.2 are pictures of the basic calculational models used in MCNP4a. These pictures were created with the two-dimensional plotter in MCNP4a and clearly indicate the explicit modeling of fuel rods in each fuel assembly. In CASMO-4, a single cell is modeled, and since CASMO-4 is a two-dimensional code, the fuel assembly hardware above and below the active fuel length is not represented. The three-dimensional MCNP4a models that included axial leakage assumed approximately 30 cm of water above and below the active fuel length. Additional models with more storage cells were generated with MCNP4a to investigate the effect of abnormal and normal conditions. These models are discussed in the appropriate section.

7.1 Region 1

The goal of the criticality calculations for the Region 1 style racks is to qualify the racks for storage of fuel assemblies with design specifications as shown in Table 5.1 and a maximum nominal initial enrichment of 5.0 wt% ^{235}U.

7.1.1 Identification of Reference Fuel Assembly

CASMO-4 calculations were performed to determine which of the two assembly types in Table 5.1 is bounding in the Region 1 racks. The presence of burnable absorbers in the fuel assembly (IFBA) was neglected for determination of the reference fuel assembly. The results in Table 7.1 shows that the NGF assembly has the highest reactivity and this assembly type is therefore used in all subsequent calculations.

7.1.2 Eccentric Fuel Assembly Positioning

The fuel assemblies are assumed to be normally located in the center of the storage rack cell. To investigate the potential reactivity effect of eccentric positioning of assemblies in the cells, MCNP4a calculations were performed with the fuel assemblies assumed to be in the corner of the storage rack cell (four-assembly cluster at closest approach). The highest reactivity, therefore, corresponds to the reference design with the fuel assemblies positioned in the center of the storage cells. The results of this calculation is shown in Table 7.6.

7.1.3 Uncertainties Due to Manufacturing Tolerances

In the calculation of the final k_{eff}, the effect of manufacturing tolerances on reactivity must be included. CASMO-4 was used to perform these calculations. As allowed in [7], the methodology employed to calculate the tolerance effects combine both the worst-case bounding value and sensitivity study approaches. The evaluations include tolerances of the rack and fuel dimensions. As for the bounding assembly, calculations are performed at an enrichment of 5.0 wt% ^{235}U. The reference condition is the condition with nominal dimensions and properties. To determine the Δk associated with a specific manufacturing tolerance, the k_{inf} calculated for the reference condition is compared to the k_{inf} from a calculation with the tolerance included. Note that for the individual parameters associated with a tolerance, no statistical approach is utilized. Instead, the full tolerance value is utilized to determine the maximum reactivity effect. All of the Δk values from the various tolerances are statistically combined (square root of the sum of the squares) to determine the final reactivity allowance for manufacturing tolerances. The fuel and rack tolerances included in this analysis are described below; the fuel density and enrichment tolerances are typical values:

Fuel Tolerances

- Increased Fuel Density: +0.165 g/cm^3
- Increased Fuel Enrichment: 0.05 wt% ^{235}U
- Fuel Rod Pitch: [redacted]
- Fuel Rod Cladding Outside Diameter: [redacted]
- Fuel Rod Cladding Thickness min: [redacted]
- Fuel Pellet Outside Diameter: [redacted]
- Guide Tube Outside Diameter: [redacted]
- Guide Tube Thickness min: [redacted]

Rack Tolerances

- Cell Inner Dimension: [redacted].
- Box Wall Thickness: [redacted].
- Cell Pitch: [redacted].
- Boral Width: [redacted].
- Poison Gap min: [redacted].
- Poison Loading min: [redacted]

Regarding the tolerance calculations, the following needs to be noted:

- In some cases it is not obvious whether an increase or decrease of the parameter will lead to an increase in reactivity. In these cases, the reactivity effect of both increase and decrease of the parameter are calculated, and the positive reactivity effect is used when calculating the statistical combination.

- The tolerance in the flux trap is conservatively captured in the tolerances of the cell ID and cell pitch, since variations of the cell ID are evaluated for a constant cell pitch and vice versa.

- Tolerance calculations were performed for pure water and borated water. The results are presented in Table 7.2 and [redacted].

7.1.4 Temperature and Water Density Effects

Pool water temperature effects on reactivity in the Region 1 racks have been calculated with CASMO-4 for an enrichment of 5.0 wt% ^{235}U for pure water and borated water. The results are presented in Table 7.3. The results show that the Region 1 spent fuel pool temperature coefficient of reactivity is negative for both cases, i.e., a lower temperature results in a higher reactivity. Consequently, the design basis calculations are evaluated at 0 °C (32 °F) for normal conditions.

In MCNP4a, the Doppler treatment and cross-sections are valid only at 300K (80.33 °F). Therefore, a Δk is determined in CASMO-4 from 32 °F to 80.33 °F, and is included in the final k_{eff} calculation as a bias. Table 7.3 shows the calculation of the bias. The temperature bias is calculated with pure water and borated water. [redacted]

7.1.5 Calculation of Maximum k_{eff}

Using the calculational model shown in Figure 5.1 and the reference 16x16 NGF fuel assemblies, the k_{eff} in the Region 1 storage racks has been calculated with MCNP4a. The calculations of the maximum k_{eff} values, based on the formula in Section 2, are shown in Table 7.4 and Table 7.5. In summary, the results show that the maximum k_{eff} of the Region 1 racks is less than 1.0 at a 95% probability at a 95% confidence level with no credit for soluble boron, and by linear interpolation, less than or equal to 0.95 with 85 ppm soluble boron.

7.1.6 Abnormal and Accident Conditions

The effects on reactivity of credible abnormal and accident conditions are examined in this section. This section identifies which of the credible abnormal or accident conditions will result in exceeding the limiting reactivity ($k_{eff} \leq 0.95$). For those accident or abnormal conditions that result in exceeding the limiting reactivity, a minimum soluble boron concentration is determined to ensure that $k_{eff} \leq 0.95$. The double contingency principal of ANS-8.1/N16.1-1975 [8] (and the USNRC letter of April 1978; see Section 3.0) specifies that it shall require at least two unlikely, independent and concurrent events to produce a criticality accident. This principle precludes the necessity of considering the simultaneous occurrence of multiple accident conditions.

7.1.6.1 Abnormal Temperature

All calculations for Region 1 are performed at a pool temperature of 32°F. As shown in Section 7.1.4 above, the temperature coefficient of reactivity is negative, therefore any increase in temperature above 32°F would cause a reduction in the reactivity. Therefore, no further evaluations of abnormal temperatures are performed.

7.1.6.2 Dropped Assembly - Horizontal

For the case in which a fuel assembly is assumed to be dropped on top of a rack, the fuel assembly will come to rest horizontally on top of the rack with a minimum separation distance from the active fuel region of more than 12 inches, which is sufficient to preclude neutron coupling (i.e., an effectively infinite separation). Consequently, the horizontal fuel assembly drop accident will not result in a significant increase in reactivity. Furthermore, the soluble boron in the spent fuel pool water assures that the true reactivity is always less than the limiting value for this dropped fuel accident.

7.1.6.3 Dropped Assembly – Vertical Into Fuel Cell

It is also possible to vertically drop an assembly into a location that might be occupied by another assembly or that might be empty. Such a vertical impact onto another assembly has previously been shown to cause no damage to either fuel assembly. A vertical drop into an empty storage cell could result in a small deformation of the baseplate. The resultant effect would be the lowering of a single fuel assembly by the amount of the deformation. This could potentially result in further misalignment between the active fuel region and the Boral. However, the amount of deformation for this drop would be small and restricted to a localized area of the rack around the storage cell where the drop occurs. Furthermore, the soluble boron in the spent fuel pool water assures that the true reactivity is always less than the limiting value for this dropped fuel accident.

7.1.6.4 Abnormal Location of a Fuel Assembly

7.1.6.4.1 Misloaded Fresh Fuel Assembly

The Region 1 racks are qualified for the storage of fresh, unburned fuel assemblies with the maximum permissible enrichment (5.0 wt% ^{235}U). Therefore, the abnormal location of a fuel assembly within normal Region 1 cells is of no concern.

7.1.6.4.2 Mislocated Fresh Fuel Assembly

The mislocation of a fresh unburned fuel assembly could, in the absence of soluble poison, result in exceeding the regulatory limit (k_{eff} of 0.95). This could possibly occur if a fresh fuel assembly of the highest permissible enrichment (5.0 wt% ^{235}U) were to be accidentally mislocated outside of a storage rack adjacent to other fuel assemblies. The results of the analysis are shown in Table 7.6 and show by linear interpolation that a soluble boron level of 193 ppm is sufficient to ensure that the maximum k_{eff} value for this condition remains at or below 0.95

7.2 Region 2

The goal of the criticality calculations for the Region 2 style racks is to qualify the racks for storage of fuel assemblies with design specifications as shown in Table 5.1 and a maximum nominal initial enrichment of 5.0 wt% ^{235}U. Specifically, the purpose of the criticality calculations is to determine the initial enrichment and burnup combinations required for the storage of spent fuel assemblies with nominal initial enrichments up to 5.0 wt% ^{235}U. Three loading configurations were analyzed to create burnup versus enrichment curves:

- a uniform loading of spent fuel meeting the burnup versus enrichment requirements of Table 7.26,
- a checkerboard loading pattern of high and low reactivity fuel with the high reactivity fuel at an enrichment of 5.0 wt% ^{235}U and a burnup of 27 GWD/MTU and the low reactivity fuel must meet the burnup versus enrichment requirements of Table 7.27;
- a checkerboard of fresh fuel up to 5.0 wt% ^{235}U and empty cell locations (i.e., fresh fuel checkerboard). This configuration bounds a checkerboard of irradiated fuel and empty cells.

7.2.1 Identification of Reference Fuel Assembly

CASMO-4 calculations were performed to determine which of the two assembly types are bounding in the Region 2 racks. In the calculations, the fuel assembly is burned in the core configuration and restarted in the rack configuration. For all assemblies, the presence of burnable absorbers in the fuel assembly (BPRA, IFBA) was neglected for determination of the reference fuel assembly (see Section 7.2.2 for a discussion the effect of burnable poison). The results are shown in Table 7.7 (selected enrichments and burnups) and show that the NGF assembly has the highest reactivity for all enrichments and burnups relative to the final burnup versus enrichment curve. [redacted]

7.2.2 Reactivity Effect of Burnable Absorbers During Depletion

The Waterford Unit 3 fuel makes use of burnable absorbers of either B_4C, erbia or integral fuel burnable absorber (IFBA) rods with a thin coating of ZrB_2 on the UO_2 pellet.

Generic studies [10] have investigated the effect that integral burnable absorbers (IBAs) have on the reactivity of spent fuel assemblies. These studies have concluded that there is a small positive reactivity effect associated with the presence of IFBA rods, which therefore bounds the negative effects of the B_4C and erbia. Therefore, only the IFBA is considered in this analysis. To determine the reactivity effect for the Waterford Unit 3 spent fuel racks, depletion calculations were performed for selected configurations of IFBA rods provided by Entergy. The reactivity of the fuel assembly with IFBA rods is compared to the reactivity of the respective fuel assembly without IFBA rods, for both the pure water case and the borated water case. The results are presented in Table 7.8 and [redacted]

7.2.3 Reactivity Effect of Axial Burnup Distribution

Initially, fuel loaded into the reactor will burn with a slightly skewed cosine power distribution. As burnup progresses, the burnup distribution will tend to flatten, becoming more highly burned in the central regions than in the upper and lower ends. At high burnup, the more reactive fuel near the ends of the fuel assembly (less than average burnup) occurs in regions of lower reactivity worth due to neutron leakage. Consequently, it would be expected that over most of the burnup history, distributed burnup fuel assemblies would exhibit a slightly lower reactivity than that calculated for the average burnup. As burnup progresses, the distribution, to some extent, tends to be self-regulating as controlled by the axial power distribution, precluding the existence of large regions of significantly reduced burnup.

Generic analytic results of the axial burnup effect for assemblies without axial blankets have been provided by Turner [9] based upon calculated and measured axial burnup distributions. These analyses confirm the minor and generally negative reactivity effect of the axially distributed burnup compared to a flat distribution, becoming positive at burnups greater than about 30 GWD/MTU. The trends observed in [9] suggest the possibility of a small positive reactivity effect above 30 GWD/MTU, increasing to slightly over 1% Δk at 40 GWD/MTU. The required burnup for the maximum enrichment is higher than 30 GWD/MTU. Therefore, a positive reactivity effect of the axially distributed burnup is possible. Calculations are conservatively performed with the axial burnup distribution shown in Table 5.3 (see Section 5.3) and with an axially constant burnup, and the higher reactivity is used in the analyses.

7.2.4 Isotopic Compositions

To perform the criticality evaluation for spent fuel in MCNP4a, the isotopic composition of the fuel is calculated with the depletion code CASMO-4 and then specified as input data for MCNP4a. The CASMO-4 calculations performed to obtain the isotopic compositions for MCNP4a were performed generically, with one calculation for each enrichment, and burnups in increments of 2.5 GWD/MTU or less. The isotopic composition for any given burnup is then determined by linear interpolation.

7.2.5 Uncertainty in Depletion Calculations

Since critical experiment data with spent fuel is not available for determining the uncertainty in burnup-dependent reactivity calculations, an allowance for uncertainty in reactivity was assigned based upon other considerations. Based on the recommendation in [7], a burnup dependent uncertainty in reactivity for burnup calculations of 5% of the reactivity decrement is used. This allowance is statistically combined with the other reactivity allowances in the determination of the maximum k_{eff} for normal conditions where assembly burnup is credited. Additionally, a sensitivity study was performed to [redacted] The results of this study are shown in Table 7.29.

7.2.6 Eccentric Fuel Assembly Positioning

The fuel assembly is assumed to be normally located in the center of the storage rack cell. In the absence of a fixed neutron absorber, the eccentric location of fuel assemblies in the storage cells may produce a positive reactivity effect. Therefore, the eccentric positioning is performed in a very conservative manner in MCNP4a, assuming 4 assemblies in the corners of the storage cell (four-assembly cluster at closest approach), and that these clusters of four assemblies are repeated throughout the rack. These calculations are performed with pure water and borated water. The results of these calculations are shown in Table 7.9 and indicate that eccentric fuel positioning results in a decrease in reactivity for both cases.

7.2.7 Uncertainties Due to Manufacturing Tolerances

In the calculation of the final k_{eff}, the effect of manufacturing tolerances on reactivity must be included. CASMO-4 was used to perform these calculations. As allowed in [7], the methodology employed to calculate the tolerance effects combine both the worst-case bounding value and sensitivity study approaches. The evaluations include tolerances of the rack and fuel dimensions. As for the bounding assembly, calculations are performed for different enrichments and burnups with a maximum value of 5.0 wt% ^{235}U. The reference condition is the condition with nominal dimensions and properties. To determine the Δk associated with a specific manufacturing tolerance, the k_{inf} calculated for the reference condition is compared to the k_{inf} from a calculation with the tolerance included. Note that for the individual parameters associated with a tolerance, no statistical approach is utilized. Instead, the full tolerance value is utilized to determine the maximum reactivity effect. All of the Δk values from the various tolerances are statistically combined (square root of the sum of the squares) to determine the final reactivity allowance for manufacturing tolerances. Only the Δk values in the positive direction (increasing reactivity) were used in the statistical combination. The fuel and rack tolerances included in this analysis are described below; the fuel density and enrichment tolerances are typical values:

Fuel Tolerances

- Increased Fuel Density: +0.165 g/cm^3
- Increased Fuel Enrichment: 0.05 wt% ^{235}U
- Fuel Rod Pitch: [redacted]
- Fuel Rod Cladding Outside Diameter: [redacted]
- Fuel Rod Cladding Thickness min: [redacted]
- Fuel Pellet Outside Diameter: [redacted]
- Guide Tube Outside Diameter: [redacted]
- Guide Tube Thickness min: [redacted]

Rack Tolerances

- Cell Inner Dimension: [redacted]
- Box Wall Thickness: [redacted]

- Poison Width: [redacted].
- Poison Gap minimum: [redacted]
- Boral B-10 Loading min: [redacted]

Regarding the tolerance calculations, the following needs to be noted:

- In some cases it is not obvious whether an increase or decrease of the parameter will lead to an increase in reactivity. In these cases, the reactivity effect of both increase and decrease of the parameter are calculated, and the positive reactivity effect is used when calculating the statistical combination.

- In the CASMO-4 model used, the tolerance calculation for the Cell ID resulted in a negative reactivity for both increases and decreases in Cell ID. Conservatively, the least negative value was used as a positive reactivity effect.

- Tolerance calculations were performed for pure water and borated water. The results are presented in Table 7.10 and Table 7.11 and [redacted]

7.2.8 Temperature and Water Density Effects

Pool water temperature effects on reactivity in the Region 2 racks have been calculated with CASMO-4 for various enrichments with a maximum value of 5.0 wt% ^{235}U and the results are presented in Table 7.12. The calculations are performed with pure water and borated water. The results show that the Region 2 spent fuel pool temperature coefficient of reactivity is negative for both cases, i.e., a higher temperature results in a lower reactivity. Consequently, all CASMO-4 calculations are evaluated at 32 °F.

In MCNP4a, the Doppler treatment and cross-sections are valid only at 300K (80.33 °F). Therefore, a Δk is determined in CASMO-4 from 32 °F to 80.33 °F, and is included in the final k_{eff} calculation as a bias. The bias is taken from the pure water cases.

7.2.9 Calculation of Maximum k_{eff}

Using the calculational model shown in Figure 5.2 and the reference 16x16 NGF fuel assembly, the k_{eff} in the Region 2 storage racks has been calculated with MCNP4a for the cases discussed in Section 7.2. The determination of the maximum k_{eff} values, based on the formula in Section 2, is shown in, for initial enrichments between 2.0 wt% ^{235}U and 5.0 wt% ^{235}U, Table 7.13 for the uniform loading case, Table 7.14 for the spent fuel checkerboard loading case, and Table 7.15 for the fresh fuel checkerboard case. A summary of the calculations for non-accident conditions of the maximum k_{eff} for spent fuel of maximum nominal enrichment of 5.0 wt% ^{235}U is shown in Table 7.16 for the uniform loading of spent fuel without soluble boron and Table 7.17 with soluble boron, Table 7.18 for the spent fuel checkerboard without soluble boron and Table 7.19

with soluble boron, and Table 7.20 for the fresh fuel checkerboard fuel. Table 7.26 and Figure 7.1 present the burnup versus enrichment requirements for the uniform loading of spent fuel and Table 7.27 and Figure 7.2 present the burnup versus enrichment requirements for the low reactivity fuel assemblies in the spent fuel checkerboard. The results show that the maximum k_{eff} of the Region 2 racks is less than 1.0 at a 95% probability and at a 95% confidence level for the three loading patterns with no credit for soluble boron, and less than 0.95 at a 95% probability and at a 95% confidence level with 524 ppm soluble boron.

7.2.10 Abnormal and Accident Conditions

The effects on reactivity of credible abnormal and accident conditions are examined in this section. This section identifies which of the credible abnormal or accident conditions will result in exceeding the limiting reactivity ($k_{eff} \leq 0.95$). For those accident or abnormal conditions that result in exceeding the limiting reactivity, a minimum soluble boron concentration is determined to ensure that $k_{eff} \leq 0.95$. The double contingency principal of ANS-8.1/N16.1-1975 [8] (and the USNRC letter of April 1978; see Section 3.0) specifies that it shall require at least two unlikely, independent and concurrent events to produce a criticality accident. This principle precludes the necessity of considering the simultaneous occurrence of multiple accident conditions.

7.2.10.1 Abnormal Temperature

All calculations for Region 2 are performed at a pool temperature of 32 °F. As shown in Section 7.2.8 above, the temperature coefficient of reactivity is negative, therefore no additional calculations are required.

7.2.10.2 Dropped Assembly - Horizontal

For the case in which a fuel assembly is assumed to be dropped on top of a rack, the fuel assembly will come to rest horizontally on top of the rack with a minimum separation distance from the active fuel region of more than 12 inches, which is sufficient to preclude neutron coupling (i.e., an effectively infinite separation). Consequently, the horizontal fuel assembly drop accident will not result in a significant increase in reactivity. Furthermore, the soluble boron in the spent fuel pool water assures that the true reactivity is always less than the limiting value for this dropped fuel accident.

7.2.10.3 Dropped Assembly - Vertical

It is also possible to vertically drop an assembly into a location that might be occupied by another assembly or that might be empty. Such a vertical impact onto another assembly has previously been shown to cause no damage to either fuel assembly. A vertical drop into an empty storage cell could result in a small deformation of the baseplate. The resultant effect would be the lowering of a single fuel assembly by the amount of the deformation. This could potentially result in further misalignment between the active fuel region and the Boral. However, the amount of deformation for this drop would be small and restricted to a localized area of the rack around the storage cell where the drop occurs. Furthermore, the reactivity increase would be small compared to the reactivity increase created by the misloading of a fresh assembly discussed in the following section. The vertical drop is therefore bounded by this misloading accident and no separate calculation is performed for the drop accident.

7.2.10.4 Abnormal Location of a Fuel Assembly

7.2.10.4.1 Misloaded Fresh Fuel Assembly

The misloading of a fresh unburned fuel assembly could, in the absence of soluble poison, result in exceeding the regulatory limit (k_{eff} of 0.95). This could possibly occur if a fresh fuel assembly of the highest permissible enrichment (5.0 wt% ^{235}U) were to be inadvertently misloaded into a storage cell intended to be used for spent fuel. The results of this accident are shown in Table 7.21.

7.2.10.4.2 Mislocated Fresh Fuel Assembly

The mislocation of a fresh unburned fuel assembly could, in the absence of soluble poison, result in exceeding the regulatory limit (k_{eff} of 0.95). This could possibly occur if a fresh fuel assembly of the highest permissible enrichment (5.0 wt% ^{235}U) were to be accidentally mislocated outside of a Region 2 storage rack adjacent to other fuel assemblies

The MCNP4a model consists of an array of Region 2 fuel storage cells with a single fresh, unburned assembly placed adjacent to the rack as close to the rack faces as possible to maximize the possible reactivity effect. The results of the analysis are shown in Table 7.21.

7.3 Interfaces Within and Between Racks

The calculations in Sections 7.1 and 7.2 assume laterally infinite arrangements of rack cells. This section evaluates the potential effect of the interfaces between and within rack modules.

7.3.1 Gaps Between Region 1 Racks

Region 1 racks have poison panels on all peripheral walls facing other racks. Furthermore, the assembly distance across the gaps between Region 1 racks is larger than the assembly distance within the racks. Under abnormal conditions, in the event of lateral rack movement, the baseplate extensions will maintain a minimum rack to rack gap that is bounded by the infinite array calculations, and no further evaluations are necessary.

7.3.2 Gaps Between Region 2 Racks

Under normal conditions, the assembly distance across the gaps between Region 2 racks is larger than the assembly distance within these racks. Since there is at least one Boral panel between adjacent assemblies for these rack to rack interfaces, the condition in the gap is therefore bounded by the infinite array calculations, and no further evaluations are necessary.

7.3.3 Gaps Between Region 1 and Region 2 Racks

According to the data provided by Entergy, Region 1 and Region 2 are separated by distances that exceed the gaps between racks within either region, and therefore the condition is bounded by the infinite array calculations and no further evaluations are necessary.

7.3.4 Patterns Within Region 2 Racks.

The Region 2 racks are qualified for three types of fuel loading pattern: a uniform loading of spent fuel, a spent fuel checkerboard loading pattern, and a fresh (or irradiated) fuel checkerboard loading pattern with empty cells. Within the Region 2 racks, various interfaces between these patterns are qualified. To show that the selected interfaces are acceptable, the following conditions are analyzed:

- An interface between the spent fuel uniform loading pattern and the spent fuel checkerboard. The configuration was chosen so that the high reactivity assembly in the spent fuel checkerboard pattern (5.0 wt%/27 GWD/MTU) is face adjacent to three low reactivity assemblies from the spent fuel checkerboard pattern (see Table 7.22), and face adjacent to 1 assembly meeting the uniform spent fuel requirement (see Table 7.22).
- Two interfaces are evaluated between checkerboards of spent fuel and fresh fuel/empty cells. The bounding case is the case where the fresh fuel assemblies face the high reactivity assembly in the spent fuel checkerboard pattern (5.0 wt%/27 GWD/MTU) on two sides, and has an empty cell on the other two sides. This condition bounds other interfaces between fresh and spent fuel, since the spent fuel with the highest permissible reactivity is used.

The interface configuration is acceptable, when the resulting k_{eff} is equivalent to, or less than the maximum k_{eff} of the individual pattern. The results are shown in Table 7.22 and show that this requirement is fulfilled for all analyzed cases and therefore:

- No restrictions are necessary between the uniform loading pattern and either of the checkerboard loading patterns (fresh or spent).
- For interfaces between the fresh fuel checkerboard and spent fuel checkerboard, the high reactivity spent fuel assembly (5.0 wt% ^{235}U, 27 GWD/MTU) may be face adjacent to no more than one fresh fuel assembly. The fresh fuel assembly may be face adjacent with up to 2 high reactivity spent fuel assemblies. Figure 7.4 shows one example of an acceptable 3x3 fresh fuel checkerboard within the center of a spent fuel checkerboard that meets these requirements.

7.4 Additional Calculations

7.4.1 Fuel Transfer Carriage Criticality

The transfer carriage is capable of accommodating two fuel assemblies at a time, carried in stainless steel boxes. The fuel transfer carriage is conservatively modeled as two fuel assemblies at 5.0 wt% ^{235}U and zero burnup separated by 5.06 inches of water only. The calculation of the criticality of the fuel transfer carriage accounts for both the carriage and the transfer tube. The results of the MCNP4a calculations are shown in Table 7.23.

Based on the design of the fuel transfer carriage, a fuel assembly could be mislocated outside the carriage. Two additional calculations were performed with a fresh fuel assembly mislocated directly adjacent to one of the two fuel assemblies in the carriage. The results of the MCNP4a calculations are shown in Table 7.23.

7.4.2 Upender Criticality

The criticality of the Upender is bounded by the calculation of the fuel transfer carriage in Section 7.4.1.

7.4.3 New Fuel Elevator Criticality

The criticality of the New Fuel Elevator is bounded by the calculation of the fuel transfer carriage in Section 7.4.1.

7.4.4 Boron Dilution Accident Evaluation

The soluble boron in the spent fuel pool water is conservatively assumed to contain a minimum of 1720 ppm under operating conditions. Significant loss or dilution of the soluble boron concentration is extremely unlikely, if not incredible. Nonetheless, an evaluation was performed based on the data provided by Entergy.

The required minimum soluble boron concentration is 524 ppm under normal conditions and 870 ppm for the most serious credible accident scenario (see Table 7.19 and Table 7.21). The volume of water in the pool is approximately 288,748 gallons. Large amounts of un-borated water would be necessary to reduce the boron concentration from 1720 ppm to 870 ppm or to 524 ppm. Abnormal or accident conditions are discussed below for either low dilution rates (abnormal conditions) or high dilution rates (accident conditions).

7.4.4.1 Low Flow Rate Dilution

Small dilution flow around pump seals and valve stems or mis-aligned valves could possibly occur in the normal soluble boron control system or related systems. Such failures might not be immediately detected. These flow rates would be of the order of 2 gpm maximum and the increased frequency of makeup flow might not be observed. However, an assumed loss flow-rate of 2 gpm dilution flow rate would require approximately 119 days to reduce the boron concentration to the minimum required 524 ppm under normal conditions or 68 days to reach the 870 ppm required for the most severe fuel handling accident. Routine surveillance measurements of the soluble boron concentration would readily detect the reduction in soluble boron concentration with ample time for corrective action.

Administrative controls require a measurement of the soluble boron concentration in the pool water at least weekly. Thus, the longest time period that a potential boron dilution might exist without a direct measurement of the boron concentration is 7 days. In this time period, an undetected dilution flow rate of 34.0 gpm would be required to reduce the boron concentration to 524 ppm. No known dilution flow rate of this magnitude has been identified. Further, a total of more than 343,000 gallons of un-borated water would be associated with the dilution event and such a large flow of un-borated water would be readily evident by high-level alarms and by visual inspection on daily walk-downs of the storage pool area.

7.4.4.2 High Flow Rate Dilution

Under certain accident conditions, it is conceivable that a high flow rate of un-borated water could flow into the spent fuel pool. As discussed in Section 5.6.4, the component cooling water makeup pumps provide makeup from the Condensate Storage Pool and have a capacity of 600 gpm. Such an accident scenario could result from the continuous operation of the Condensate Storage Pool pump and a flow rate of up to 600 gpm which could possibly contribute large amounts of un-borated water into the spent fuel.

Conservatively assuming that all the un-borated water from the pump poured into the pool and further assuming instantaneous mixing of the un-borated water with the pool water, it would take approximately 572 minutes to dilute the soluble boron concentration to 524 ppm, which is the minimum required concentration to maintain k_{eff} below 0.95 under normally operating conditions. In this dilution accident, some 343,000 gallons of water would be released into the spent fuel pool and multiple alarms would have alerted the control room of the accident consequences (including the fuel pool high-level alarm and the Fuel Handling Building sump high level alarm and Liquid Waste Management Trouble alarm). For this high flow rate condition, 328 minutes would be required to reach the 870 ppm required for the most severe fuel handling accident.

It is not considered credible that multiple alarms would fail or be ignored or that the spilling of large volumes of water would not be observed. Therefore, such a major failure would be detected in sufficient time for corrective action to avoid violation of an Technical Specification LCO and to assure that the health and safety of the public is protected.

7.4.5 Temporary Storage Racks

The results of the TSR are summarized in Table 7.24. These results show that the TSR is qualified for loading fuel assemblies with an initial enrichment of up to 5.0 wt% ^{235}U. Based on information provided by Entergy, a fuel assembly may be mislocated on the exterior of the TSR. The mislocated fresh fuel assembly was modeled at the closest approach (See Table 5.5). For simplification, the following tolerances are included in the design basis model: fuel density, lattice pitch and enrichment (See Table 5.5). The results of the mislocated case and the necessary soluble boron amount are present in Table 7.24.

7.4.6 Fuel Pin Storage Container

The FPSC calculation involved comparing the reactivity of the FPSC to three cases of NGF fuel assemblies under equivalent modeling conditions: a fresh fuel assembly, a burnup of 27 GWD/MTU and a burnup of 33.4 GWD/MTU, all at 5.0 wt% ^{235}U. These three cases match the most reactive fuel assembly for the three loading patterns analyzed in the main body of the report. The results of these comparisons can be seen in Table 7.25. Therefore the FPSC can be placed in any location intended for fresh or spent fuel.

7.4.7 New Fuel Storage Vault

The maximum calculated reactivity of the NFV is listed in Table 7.28. The calculated reactivity as a function of water density is also shown in Figure 7.7. The results show that the optimum moderator density occurs at 100% water density and this maximum k_{eff} is below the regulatory limit.

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9. S.E. Turner, "Uncertainty Analysis - Burnup Distributions," presented at the DOE/SANDIA Technical Meeting on Fuel Burnup Credit, Special Session, ANS/ENS Conference, Washington, D.C., November 2, 1988.

10. "Study of the Effect of Integral Burnable Absorbers for PWR Burnup Credit," NUREG/CR-6760, ORNL/TM-2000-321, March 2002.

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[1] Note: The revision status of Holtec documents cited above is subject to updates as the project progresses. This document will be revised if a revision to any of the above-referenced Holtec work materially affects the instructions, results, conclusions or analyses contained in this document. Otherwise, a revision to this document will not be made and the latest revision of the referenced Holtec documents shall be assumed to supercede the revision numbers cited above. The Holtec Project Manager bears the undivided responsibility to ensure that there is no intra-document conflict with respect to the information contained in all Holtec generated documents on a safety-significant project. The latest revision number of all documents produced by Holtec International in a safety significant project is readily available from the company's electronic network.

11. HI-2094370R0, "CASMO-4 Benchmark for Spent Fuel Pool Criticality Analysis."

Table 5.1
Fuel Assembly Specification

Assembly Type	16x16 Standard	16x16 NGF
Stack Density, g/cm^3	10.412	10.522
Fuel Rod Pitch, in	0.506	0.506
Number of Fuel Rods	236	236
Number of Guide Tubes	5	5
Fuel Rod Clad OD, in	0.382	0.374
Fuel Rod Clad ID, in	0.332	0.329
Active Length, in	149.61-150.0	150.0
Fuel Pellet Diameter, in	0.325	0.3225
Guide Tube OD, in	0.98	0.98
Guide Tube ID, in	0.9	0.9
ZrB_2 Rod Coating Loading (mgm ^{10}B/inch)	3.14	3.14
ZrB_2 Rod Coating Thickness (inches)	0.0004167	0.000417
ZrB_2 Rod Coating Length (inches)	136	138
Fuel Assembly Width (min), in.	n/a	8.125
Bottom of Active Fuel to Bottom of Fuel Assembly, in.	n/a	~5.402

Table 5.2
Core Operating Parameter for Depletion Analyses

Parameter	Value
Soluble Boron Concentration (bounding cycle average), ppm	1000
Reactor Specific Power, MW/MTU	40.5
Core Average Fuel Temperature, °F	1041.0
Core Average Moderator Temperature at the Top of the Active Region, °F	614.0
In-Core Assembly Pitch, Inches	8.18

Table 5.3
Axial Burnup Profiles

Node Center (cm)	Relative Burnup ≤ 25 GWD/MT	Relative Burnup > 25 GWD/MT
7.62	0.54	0.593
22.86	0.773	0.819
38.1	0.921	0.961
53.34	1.013	1.028
68.58	1.055	1.051
83.82	1.065	1.057
99.06	1.064	1.058
114.3	1.061	1.058
129.54	1.058	1.057
144.78	1.056	1.056
160.02	1.054	1.055
175.26	1.053	1.054
190.5	1.052	1.054
205.74	1.051	1.053
220.98	1.05	1.051
236.22	1.047	1.049
251.46	1.046	1.048
266.7	1.044	1.046
281.94	1.04	1.043
297.18	1.031	1.036
312.42	0.994	1.021
327.66	0.92	0.966
342.9	0.81	0.873
358.14	0.655	0.725
373.38	0.441	0.508

Table 5.4

Storage Rack and Spent Fuel Pool Parameter Specification

Region 1		
Parameter	**Value**	**Tolerance**
Cell ID, in	8.5	[redacted]
Cell Wall thickness, in	0.075	[redacted]
[2]Cell Pitch, in	10.185	[redacted]
Boundary Sheathing Thickness, in	0.075	n/a
Inner Sheathing Thickness, in	0.0235	n/a
[3]Poison Thickness, in	0.089	n/a
Poison Width, in	7.25	[redacted]
Poison Gap, (nominal) in	0.096	[redacted]
Flux Trap (nominal) in	1.3	[redacted]
B-10 Loading, (nom) g/cm^2	0.028	[redacted]
Region 2		
Parameter	**Value**	**Tolerance**
Cell ID, in	8.5	[redacted]
Cell Wall thickness, in	0.075	n/a
Cell Pitch, in	8.692	[redacted]
Boundary Sheathing Thickness, in	0.075	n/a
Inner Sheathing Thickness, in	0.035	n/a
Poison Thickness, in	0.075	n/a
Poison Width, in	7.25	[redacted]
Poison Gap, in (nominal)	0.082	[redacted]
B-10 Loading, (nom) g/cm^2	0.0216	[redacted]
Additional Spent Fuel Pool Information		
Parameter	**Value**	**Tolerance**
Soluble Boron Concentration, ppm	1720	n/a
Spent Fuel Pool Volume, cf	38,600	n/a
Fuel Transfer Carriage Gap, in	5.06	n/a
Refueling Water Storage Pool (min), ppm	2050	n/a
Refueling Water Pool Purification Pump, gpm	150	n/a
Component Cooling Water Makeup Pumps, gpm	600	n/a

[2] Note that [4] indicates a larger cell-cell pitch for the North-South direction. The value used is bounding.
[3] Note that the actual model used 0.075 inches for the poison thickness for conservatism.

Table 5.5

Reactor Building Temporary Storage Rack

Parameter	Value
Number of Storage Cells	5
Pitch, in.	18 [redacted]
Rack Opening, in.	8.62 [redacted]
Canal Wall to Cell Center, in.	8.06
Distance from Outside Edge of Cell Wall to Outside Edge of Structural Material of Cell, in.	2.25
Enrichment Tolerance, wt% ^{235}U	± 0.05
Fuel Density Tolerance, g UO_2/cm^3	±0.165
Rack Pitch Spacing[4] Tolerance, in.	[redacted]

Fuel Pin Storage Container

Parameter	Value
Steel Tube Outer Diameter[5], in.	0.625
Steel Tube Thickness, in.	0.035
Steel Tube Pitch, in.	0.917

[4] The rack pitch spacing is used to account for the possible gaps between the fuel assembly and rack inner wall. This value is used in the place of the much smaller pitch tolerance listed.
[5] Note: 4 tubes have a larger outer diameter; the smaller diameter is used to conservatively model less steel.

Table 5.6

New Fuel Vault Parameters

Parameter	Value
Vault North-South width, ft.	27.5
Vault East-West width, ft.	29.25
Rack Cell Opening, in.	8.9375
Thickness of Redwood Planks, in.	1.5
Rack Cell Pitch, in.	21
East-West Rack Module Center-to-Center Cell Separation, in.	49
North-South Rack Module Center-to-Center Cell Separation, in.	58
Distance from Fuel Assembly Center to North Wall, in.	12.25
Distance from Fuel Assembly Center to East and West Wall, in.	60
Distance from Fuel Assembly Center to South Wall, in.	91.75
Depth of Rack Cell, in.	190

Table 7.1

Results of the Region 1 Reference Fuel Assembly Calculations

Assembly Type at 5.0 wt% U-235	0 ppm Soluble Boron		[redacted]	
	k_{inf}	Delta k_{inf}	k_{inf}	Delta k_{inf}
Standard	0.9164	0.0104	[redacted]	[redacted]
NGF	0.9268		[redacted]	

Table 7.2

Region 1 Manufacturing Tolerances and Uncertainty Calculations

	0 ppm Soluble Boron		[redacted]	
Parameter	k_{inf}	Delta k_{inf}	k_{inf}	Delta k_{inf}
Reference Case CASMO	0.9268	n/a	[redacted]	[redacted]
Storage Cell ID Increase	0.9370	0.0102	[redacted]	[redacted]
Storage Cell ID Decrease	0.9205	-0.0063	[redacted]	[redacted]
Storage Cell Pitch Increase	0.9184	-0.0084	[redacted]	[redacted]
Storage Cell Pitch Decrease	0.9350	0.0082	[redacted]	[redacted]
Storage Cell Poison Width Increase	0.9250	-0.0018	[redacted]	[redacted]
Storage Cell Poison Width Decrease	0.9289	0.0021	[redacted]	[redacted]
Storage Cell Poison Gap Minimum	0.9263	-0.0005	[redacted]	[redacted]
Storage Cell Box Wall Decrease	0.9242	-0.0026	[redacted]	[redacted]
Storage Cell Box Wall Increase	0.9285	0.0017	[redacted]	[redacted]
Storage Cell Poison B-10 Loading Min	0.9291	0.0023	[redacted]	[redacted]
Fuel Rod Pitch Increase	0.9277	0.0009	[redacted]	[redacted]
Fuel Rod Pitch Decrease	0.9259	-0.0009	[redacted]	[redacted]
Fuel Rod Clad OD Increase	0.9248	-0.0020	[redacted]	[redacted]
Fuel Rod Clad OD Decrease	0.9288	0.0020	[redacted]	[redacted]
Fuel Rod Clad Thickness Minimum	0.9267	-0.0001	[redacted]	[redacted]
Fuel Pellet OD Increase	0.9271	0.0003	[redacted]	[redacted]
Fuel Pellet OD Decrease	0.9265	-0.0003	[redacted]	[redacted]
Guide Tube OD Increase	0.9268	0.0000	[redacted]	[redacted]
Guide Tube OD Decrease	0.9268	0.0000	[redacted]	[redacted]
Guide Tube Thickness Minimum	0.9272	0.0004	[redacted]	[redacted]
Fuel Pellet Enrichment Increase	0.9284	0.0016	[redacted]	[redacted]
Fuel Pellet Density Increase	0.9285	0.0017	[redacted]	[redacted]
Statistical Combination	0.0140		[redacted]	

Shaded areas indicate where proprietary information has been removed.

Table 7.3

Region 1 Temperature and Water Density Effects Results (5.0 wt% U-235)

Case	0 ppm Soluble Boron		[redacted]	
	k_{inf}	Delta k_{inf}	k_{inf}	Delta k_{inf}
Ref 32 F	0.9268	n/a	[redacted]	[redacted]
39.2 F	0.9266	-0.0002	[redacted]	[redacted]
68 F	0.9253	-0.0015	[redacted]	[redacted]
80.33 F	0.9244	-0.0024	[redacted]	[redacted]
140 F	0.9188	-0.0080	[redacted]	[redacted]
255 F 0% voids	0.9028	-0.0240	[redacted]	[redacted]
255 F 10% voids	0.8681	-0.0587	[redacted]	[redacted]
255 F 20% voids	0.8295	-0.0973	[redacted]	[redacted]
Bias to 80.33 F	0.0024		[redacted]	

Table 7.4

Summary of the Criticality Safety Analysis for Region 1 Without Soluble Boron

Uncertainties:		
[redacted]	±	[redacted]
MCNP4a Code Calculation Statistics (95%/95%,2.0xσ)	±	0.0014
Fuel Eccentricity		negative
Manufacturing Tolerances	±	0.0140
Statistical Combination of Uncertainties	±	0.0169
Reference keff (MCNP4a)		0.9354
Total Uncertainty (above)		0.0169
Bias to 80.33 °F		0.0024
[redacted]		[redacted]
Maximum keff		**0.9558**
Regulatory Limit keff		1.0000

Table 7.5

Summary of the Criticality Safety Analysis for Region 1 with Soluble Boron Requirement

Soluble Boron ppm		85
Uncertainties:		
[redacted]	±	[redacted]
MCNP4a Code Calculation Statistics (95%/95%,2.0xσ)	±	0.0014
Fuel Eccentricity		negative
Manufacturing Tolerances	±	0.0140
Statistical Combination of Uncertainties	±	0.0169
Reference keff (MCNP4a)		0.9246
Total Uncertainty (above)		0.0169
Bias to 80.33 °F		0.0024
[redacted]		[redacted]
Maximum keff		**0.9450**
Regulatory Limit keff		0.9500

Shaded areas indicate where proprietary information has been removed.

Table 7.6

Results of Associated Region 1 Reactivity Calculations

Eccentric Positioning Case	
Case	**k_{eff}**
Reference	0.9354
Eccentric	0.9332
Delta-k	-0.0022
Soluble Boron Case	
ppm Boron	**k_{eff}**
0	0.9354
200	0.9099
Target k_{eff}	0.9246
Calculated ppm	85
Mislocated FA Case	
ppm Boron	**k_{eff}**
0	0.9510
400	0.8962
Target k_{eff}	0.9246
Calculated ppm	193

Table 7.7 (1 of 2)
Region 2 Calculations for the Reference Fuel Assembly

Enrichment		2.0 wt% ^{235}U	
Burnup (GWD/MTU)	Standard	NGF	Δk
0.0	0.9568	0.9631	0.0063
0.1	0.9537	0.9600	0.0063
2.0	0.9391	0.9448	0.0057
4.0	0.9231	0.9283	0.0052

Enrichment		3.5 wt% ^{235}U	
Burnup (GWD/MTU)	Standard	NGF	Δk
0.0	1.1113	1.1179	0.0067
0.1	1.1089	1.1156	0.0067
2.0	1.0887	1.0952	0.0064
4.0	1.0719	1.0782	0.0062
6.0	1.0547	1.0607	0.0061
8.0	1.0377	1.0435	0.0058
10.0	1.0211	1.0267	0.0055
11.0	1.0130	1.0184	0.0054
12.5	1.0012	1.0063	0.0052
15.0	0.9819	0.9867	0.0048
17.5	0.9631	0.9674	0.0043
20.0	0.9446	0.9484	0.0038
22.5	0.9265	0.9298	0.0033
25.0	0.9088	0.9115	0.0027

Table 7.7 (2 of 2)

Enrichment				5.0 wt% U-235		
Soluble Boron	0 ppm			[redacted]		
Burnup (GWD/MTU)	Standard kinf	NGF kinf	Delta kinf	Standard kinf	NGF kinf	Delta kinf
0.0	1.1933	1.1998	0.0065	[redacted]	[redacted]	[redacted]
0.1	1.1915	1.1980	0.0065	[redacted]	[redacted]	[redacted]
2.0	1.1708	1.1773	0.0064	[redacted]	[redacted]	[redacted]
4.0	1.1559	1.1623	0.0064	[redacted]	[redacted]	[redacted]
6.0	1.1406	1.1470	0.0064	[redacted]	[redacted]	[redacted]
8.0	1.1254	1.1317	0.0063	[redacted]	[redacted]	[redacted]
10.0	1.1106	1.1168	0.0062	[redacted]	[redacted]	[redacted]
11.0	1.1034	1.1095	0.0062	[redacted]	[redacted]	[redacted]
12.5	1.0927	1.0987	0.0061	[redacted]	[redacted]	[redacted]
15.0	1.0753	1.0812	0.0059	[redacted]	[redacted]	[redacted]
17.5	1.0583	1.0640	0.0056	[redacted]	[redacted]	[redacted]
20.0	1.0417	1.0471	0.0054	[redacted]	[redacted]	[redacted]
22.5	1.0254	1.0305	0.0051	[redacted]	[redacted]	[redacted]
25.0	1.0094	1.0141	0.0048	[redacted]	[redacted]	[redacted]
27.5	0.9934	0.9979	0.0044	[redacted]	[redacted]	[redacted]
30.0	0.9777	0.9817	0.0040	[redacted]	[redacted]	[redacted]
32.5	0.9620	0.9656	0.0036	[redacted]	[redacted]	[redacted]
35.0	0.9465	0.9497	0.0032	[redacted]	[redacted]	[redacted]
37.5	0.9311	0.9338	0.0027	[redacted]	[redacted]	[redacted]
40.0	0.9158	0.9180	0.0022	[redacted]	[redacted]	[redacted]
42.5	0.9006	0.9023	0.0017	[redacted]	[redacted]	[redacted]
45.0	0.8856	0.8868	0.0012	[redacted]	[redacted]	[redacted]

Table 7.8 (1 of 2)

Region 2 Calculations for NGF Fuel IFBA Rods Reactivity Effect

Soluble Boron	0 ppm					
wt% U235	3.5			5.0		
Number of IFBA Rods / Burnup GWD/MTU	0	148	Delta k	0	148	Delta k
0.0	1.1179	0.8007	-0.3172	1.1998	0.9152	-0.2846
0.1	1.1156	0.8026	-0.3130	1.1980	0.9162	-0.2818
2.0	1.0952	0.8564	-0.2388	1.1773	0.9476	-0.2297
4.0	1.0782	0.9013	-0.1769	1.1623	0.9774	-0.1848
6.0	1.0607	0.9330	-0.1278	1.1470	1.0000	-0.1469
8.0	1.0435	0.9537	-0.0898	1.1317	1.0165	-0.1153
10.0	1.0267	0.9655	-0.0611	1.1168	1.0276	-0.0892
11.0	1.0184	0.9686	-0.0498	1.1095	1.0315	-0.0780
12.5	1.0063	0.9704	-0.0359	1.0987	1.0353	-0.0635
15.0	0.9867	0.9673	-0.0194	1.0812	1.0371	-0.0441
17.5	0.9674	0.9585	-0.0089	1.0640	1.0343	-0.0297
20.0	0.9484	0.9461	-0.0024	1.0471	1.0279	-0.0192
22.5	0.9298	0.9315	0.0017	1.0305	1.0188	-0.0117
25.0	0.9115	0.9156	0.0041	1.0141	1.0076	-0.0065
27.5	0.8935	0.8990	0.0055	0.9979	0.9951	-0.0028
30.0	0.8758	0.8821	0.0063	0.9817	0.9815	-0.0002
32.5	0.8585	0.8653	0.0067	0.9656	0.9673	0.0016
35.0	0.8417	0.8486	0.0069	0.9497	0.9525	0.0029
37.5	0.8253	0.8323	0.0070	0.9338	0.9375	0.0037
40.0	0.8095	0.8165	0.0070	0.9180	0.9223	0.0043
42.5	0.7942	0.8011	0.0069	0.9023	0.9070	0.0047
45.0	0.7796	0.7864	0.0068	0.8868	0.8918	0.0050

Table 7.8 (2 of 2)

Soluble Boron	[redacted]					
wt% U235	**3.5**			**5.0**		
Number of IFBA Rods / **Burnup GWD/MTU**	**0**	**148**	**Delta k**	**0**	**148**	**Delta k**
0.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
0.1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
2.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
4.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
6.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
8.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
10.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
11.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
12.5	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
15.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
17.5	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
20.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
22.5	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
25.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
27.5	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
30.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
32.5	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
35.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
37.5	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
40.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
42.5	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
45.0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 7.9 (1 of 2)

Region 2 Calculations for Eccentric Fuel Positioning

Soluble Boron	**0 ppm**	
Case	**Calculated k_{eff}**	**Delta k**
Reference Uniform Loading	0.9570	-0.0053
Spent Fuel Uniform Loading Eccentric Positioning	0.9517	
Reference Spent Fuel Checkerboard Loading	0.9719	-0.0044
Spent Fuel Checkerboard Loading Eccentric Positioning	0.9675	
Reference Fresh Checkerboard	0.8256	-0.0032
Fresh Fuel Checkerboard Eccentric Positioning	0.8224	

Table 7.9 (2 of 2)

Soluble Boron	600 ppm	
Case	**Calculated k_{eff}**	**Delta k**
Reference Uniform Loading	0.8842	-0.0003
Spent Fuel Uniform Loading Eccentric Positioning	0.8839	
Reference Spent Fuel Checkerboard Loading	0.9023	-0.0025
Spent Fuel Checkerboard Loading Eccentric Positioning	0.8998	
Reference Fresh Checkerboard	0.7672	-0.0041
Fresh Fuel Checkerboard Eccentric Positioning	0.7631	

Table 7.10 (1 of 2)

Region 2 Calculations for Manufacturing Tolerance Uncertainties for Fuel Storage Cell

Burnup GWD/MTU	Enrichment	Ref Case	ID +	ID -	Poison Width +	Poison Width -	Poison Gap Min	Box Wall +	Box Wall -	B-10 Loading Min	Statistical Combo
0.0	2	0.9631	-0.0023	-0.0013	-0.0020	0.0026	0.0001	0.0001	-0.0001	0.0034	0.0045
2.0	2	0.9448	-0.0024	-0.0012	-0.0020	0.0025	0.0001	0.0001	-0.0001	0.0034	0.0043
4.0	2.5	0.9897	-0.0029	-0.0009	-0.0021	0.0026	0.0001	0.0001	-0.0001	0.0035	0.0045
8.0	2.5	0.9534	-0.0028	-0.0008	-0.0020	0.0025	0.0001	0.0001	-0.0001	0.0034	0.0043
11.0	3	0.9769	-0.0030	-0.0006	-0.0021	0.0025	0.0001	0.0000	-0.0001	0.0035	0.0043
15.0	3	0.9443	-0.0029	-0.0006	-0.0020	0.0024	0.0001	0.0001	-0.0001	0.0034	0.0042
15.0	3.5	0.9867	-0.0032	-0.0004	-0.0021	0.0026	0.0001	0.0001	-0.0001	0.0035	0.0044
22.5	3.5	0.9298	-0.0029	-0.0005	-0.0020	0.0024	0.0001	0.0000	-0.0001	0.0033	0.0041
22.5	4	0.9679	-0.0032	-0.0003	-0.0020	0.0025	0.0001	0.0000	-0.0001	0.0034	0.0043
27.5	4	0.9326	-0.0030	-0.0004	-0.0020	0.0024	0.0001	0.0000	-0.0001	0.0033	0.0041
27.5	4.5	0.9673	-0.0032	-0.0002	-0.0020	0.0025	0.0001	0.0000	-0.0001	0.0034	0.0042
32.5	4.5	0.9338	-0.0031	-0.0003	-0.0020	0.0024	0.0001	0.0000	-0.0001	0.0033	0.0041
32.5	5	0.9656	-0.0033	-0.0002	-0.0020	0.0025	0.0001	0.0000	-0.0001	0.0034	0.0042
40.0	5	0.9180	-0.0030	-0.0002	-0.0019	0.0024	0.0001	0.0000	-0.0001	0.0032	0.0040

Table 7.10 (2 of 2)

Region 2 Manufacturing Tolerance Uncertainties Soluble Boron Effect Comparison (5.0 wt% U-235)

[redacted]										
Burnup GWD/MTU	Ref Case	ID +	ID -	Poison Width +	Poison Width -	Poison Gap Min	Box Wall +	Box Wall -	B-10 Loading Min	Statistical Combo.
0.0	1.1185	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
20.0	0.9757	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
40.0	0.8512	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
60.0	0.7366	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
0 ppm Soluble Boron										
Burnup GWD/MTU	Ref Case	ID +	ID -	Poison Width +	Poison Width -	Poison Gap Min	Box Wall +	Box Wall -	B-10 Loading Min	Statistical Combo.
0.0	1.1998	-0.0046	0.0002	-0.0025	0.0031	0.0001	0.0001	-0.0002	0.0043	0.0053
20.0	1.0471	-0.0038	0.0000	-0.0022	0.0027	0.0001	0.0000	-0.0001	0.0037	0.0046
40.0	0.9180	-0.0030	-0.0002	-0.0019	0.0024	0.0001	0.0000	-0.0001	0.0032	0.0040
60.0	0.7986	-0.0024	-0.0004	-0.0017	0.0021	0.0001	0.0000	-0.0001	0.0028	0.0035

Table 7.11 (1 of 2)
Region 2 Calculations for Fuel Tolerance Uncertainties

Burnup GWD/ MTU	Enr	Ref Case	Pitch +	Pitch -	Clad OD +	Clad OD -	Clad Thickness Min	Fuel Pellet OD +	Fuel Pellet OD -	Guide Tube OD +	Guide Tube OD -	Guide Tube Thickness Min	Fuel Pellet Enr +	Fuel Pellet Density +	Statistical Combo.
0.0	2.0	0.9631	0.0007	-0.0007	-0.0009	0.0009	0.0005	0.0004	-0.0004	0.0000	0.0000	0.0002	0.0074	0.0022	0.0079
2.0	2.0	0.9448	0.0007	-0.0007	-0.0008	0.0008	0.0005	0.0004	-0.0004	0.0000	0.0000	0.0002	0.0070	0.0022	0.0075
4.0	2.5	0.9897	0.0008	-0.0008	-0.0008	0.0008	0.0005	0.0004	-0.0004	0.0000	0.0000	0.0002	0.0054	0.0019	0.0059
8.0	2.5	0.9534	0.0008	-0.0008	-0.0007	0.0007	0.0005	0.0004	-0.0004	0.0000	0.0000	0.0002	0.0054	0.0020	0.0059
11.0	3.0	0.9769	0.0009	-0.0009	-0.0008	0.0007	0.0005	0.0003	-0.0004	0.0000	0.0000	0.0002	0.0045	0.0018	0.0050
15.0	3.0	0.9443	0.0008	-0.0008	-0.0006	0.0006	0.0004	0.0004	-0.0004	0.0000	0.0000	0.0002	0.0046	0.0020	0.0051
15.0	3.5	0.9867	0.0009	-0.0009	-0.0007	0.0007	0.0004	0.0003	-0.0003	0.0000	0.0000	0.0002	0.0039	0.0017	0.0044
22.5	3.5	0.9298	0.0009	-0.0008	-0.0005	0.0005	0.0004	0.0004	-0.0004	0.0000	0.0000	0.0001	0.0041	0.0020	0.0047
22.5	4.0	0.9679	0.0009	-0.0009	-0.0007	0.0006	0.0004	0.0003	-0.0004	0.0000	0.0000	0.0002	0.0035	0.0017	0.0041
27.5	4.0	0.9326	0.0009	-0.0009	-0.0005	0.0005	0.0004	0.0004	-0.0004	0.0000	0.0000	0.0001	0.0037	0.0019	0.0043
27.5	4.5	0.9673	0.0010	-0.0009	-0.0006	0.0006	0.0004	0.0003	-0.0003	0.0000	0.0000	0.0002	0.0032	0.0016	0.0038
32.5	4.5	0.9338	0.0009	-0.0009	-0.0005	0.0005	0.0004	0.0004	-0.0004	0.0000	0.0000	0.0001	0.0033	0.0018	0.0040
32.5	5.0	0.9656	0.0010	-0.0010	-0.0006	0.0006	0.0004	0.0003	-0.0003	0.0000	0.0000	0.0002	0.0030	0.0015	0.0036
40.0	5.0	0.9180	0.0009	-0.0009	-0.0004	0.0004	0.0004	0.0004	-0.0004	0.0000	0.0000	0.0001	0.0031	0.0019	0.0039

Table 7.11 (2 of 2)

Region 2 Fuel Tolerance Uncertainties Soluble Boron Effect Comparison (5.0 wt% U-235)

[redacted]														
Burnup GWD/MTU	Ref Case	Pitch +	Pitch -	Clad OD +	Clad OD -	Clad Thickness Min	Fuel Pellet OD +	Fuel Pellet OD -	Guide Tube OD +	Guide Tube OD -	Guide Tube Thickness Min	Fuel Pellet Enr +	Fuel Pellet Density +	Statistical Combo.
0.0	1.1185	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
20.0	0.9757	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
40.0	0.8512	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
60.0	0.7366	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
0 ppm Soluble Boron														
Burnup GWD/MTU	Ref Case	Pitch +	Pitch -	Clad OD +	Clad OD -	Clad Thickness Min	Fuel Pellet OD +	Fuel Pellet OD -	Guide Tube OD +	Guide Tube OD -	Guide Tube Thickness Min	Fuel Pellet Enr +	Fuel Pellet Density +	Statistical Combo.
0.0	1.1998	0.0012	-0.0012	-0.0011	0.0011	0.0005	0.0002	-0.0002	0.0000	0.0000	0.0003	0.0021	0.0012	0.0029
20.0	1.0471	0.0011	-0.0011	-0.0009	0.0009	0.0004	0.0002	-0.0002	0.0000	0.0000	0.0003	0.0027	0.0011	0.0032
40.0	0.9180	0.0009	-0.0009	-0.0004	0.0004	0.0004	0.0004	-0.0004	0.0000	0.0000	0.0001	0.0031	0.0019	0.0039
60.0	0.7986	0.0008	-0.0007	0.0003	-0.0003	0.0004	0.0008	-0.0008	0.0000	0.0000	-0.0001	0.0031	0.0033	0.0047

Table 7.12 (1 of 2)

Region 2 Calculations for Pool Temperature Tolerance Uncertainties

Burnup GWD/MTU	Enr	Ref Case T = 32 F	T = 39.2 F	T = 80.33 F	T = 255 F, 0% Voids	T = 255 F, 10% Voids	T = 255 F, 20% Voids
0.0	2.0	0.9631	-0.0008	-0.0056	-0.0318	-0.0495	-0.0714
2.0	2.0	0.9448	-0.0007	-0.0051	-0.0291	-0.0462	-0.0675
4.0	2.5	0.9897	-0.0006	-0.0046	-0.0273	-0.0458	-0.0684
8.0	2.5	0.9534	-0.0005	-0.0041	-0.0248	-0.0431	-0.0655
11.0	3.0	0.9769	-0.0005	-0.0038	-0.0242	-0.0435	-0.0667
15.0	3.0	0.9443	-0.0004	-0.0035	-0.0225	-0.0414	-0.0643
15.0	3.5	0.9867	-0.0004	-0.0036	-0.0234	-0.0433	-0.0671
22.5	3.5	0.9298	-0.0004	-0.0031	-0.0208	-0.0400	-0.0631
22.5	4.0	0.9679	-0.0004	-0.0032	-0.0219	-0.0419	-0.0658
27.5	4.0	0.9326	-0.0003	-0.0029	-0.0203	-0.0399	-0.0633
27.5	4.5	0.9673	-0.0003	-0.0030	-0.0213	-0.0416	-0.0658
32.5	4.5	0.9338	-0.0003	-0.0028	-0.0199	-0.0398	-0.0635
32.5	5.0	0.9656	-0.0003	-0.0029	-0.0208	-0.0414	-0.0657
40.0	5.0	0.9180	-0.0003	-0.0025	-0.0189	-0.0388	-0.0625

Table 7.12 (2 of 2)

Region 2 Calculations for Pool Temperature Tolerance Uncertainties Soluble Boron Effect Comparison (5.0 wt% U-235)

600 ppm Soluble Boron							
Burnup GWD/MTU	Enr	Ref Case T = 32 F	T = 39.2 F	T = 80.33 F	T = 255 F, 0% Voids	T = 255 F, 10% Voids	T = 255 F, 20% Voids
0.0	5	1.1185	-0.0003	-0.0022	-0.0153	-0.0277	-0.0442
20.0	5	0.9757	-0.0002	-0.0020	-0.0138	-0.0268	-0.0437
60.0	5	0.7366	0.0000	-0.0003	-0.0047	-0.0153	-0.0292
0 ppm Soluble Boron							
Burnup GWD/MTU	Enr	Ref Case T = 32 F	T = 39.2 F	T = 80.33 F	T = 255 F, 0% Voids	T = 255 F, 10% Voids	T = 255 F, 20% Voids
0.0	5	1.1998	-0.0004	-0.0034	-0.0248	-0.0462	-0.0718
20.0	5	1.0471	-0.0004	-0.0033	-0.0233	-0.0444	-0.0695
60.0	5	0.7986	-0.0001	-0.0015	-0.0129	-0.0307	-0.0518

Table 7.13

Region 2 Results for the Spent Fuel Uniform Loading

Enrichment (wt% U235)	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Burnup (GWD/MTU)	0.0	6.4	12.4	18.3	24.3	28.9	34.1
CASMO Burnup for Tolerances	0.0	4.0	11.0	15.0	22.5	27.5	32.5
CASMO Burnup for Depletion Uncertainty	n/a	8.0	12.5	20.0	25.0	30.0	35.0
Depletion Uncertainty	0.0000	0.0038	0.0057	0.0085	0.0100	0.0113	0.0125
Manufacturing Uncertainty	0.0045	0.0045	0.0043	0.0044	0.0043	0.0042	0.0042
Fuel Uncertainty	0.0079	0.0059	0.0050	0.0044	0.0041	0.0038	0.0036
Calculational Uncertainty	0.0012	0.0012	0.0014	0.0014	0.0012	0.0012	0.0014
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total Uncertainty	0.0131	0.0125	0.0129	0.0141	0.0150	0.0158	0.0166
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Temperature Bias	0.0056	0.0046	0.0038	0.0036	0.0032	0.0030	0.0029
IFBA Bias	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070
Adjusted k_{eff} (0.995-corrections)	**0.9681**	**0.9697**	**0.9701**	**0.9691**	**0.9687**	**0.9680**	**0.9673**
Adjusted k_{eff} (0.945-corrections)	**0.9181**	**0.9197**	**0.9201**	**0.9191**	**0.9187**	**0.9180**	**0.9173**
MCNP k_{eff} 0 ppm Boron	0.9613	0.9697	0.9701	0.9691	0.9687	0.9680	0.9673
MCNP k_{eff} 600 ppm Boron	0.8560	n/a	n/a	0.8901	n/a	n/a	0.9003
Total k_{eff} 0 ppm Boron	**0.9950**	**0.9950**	**0.9950**	**0.9950**	**0.9950**	**0.9950**	**0.9950**
Total k_{eff} with 600 ppm Boron	**0.8829**	n/a	n/a	**0.9169**	n/a	n/a	**0.9271**
Normal Conditions Interpolated Boron Concentration to Adjusted k_{eff}	**246**	n/a	n/a	**379**	n/a	n/a	**448**
Mislocated k_{eff} 0 ppm Boron	n/a	**1.0085**	n/a	**1.0046**	n/a	n/a	**1.0011**
Mislocated k_{eff} 600 ppm Boron	n/a	**0.8996**	n/a	**0.9017**	n/a	n/a	**0.9048**
Mislocated Conditions Interpolated Boron Concentration to Adjusted k_{eff}	n/a	**489**	n/a	**498**	n/a	n/a	**522**
Misloaded k_{eff} 0 ppm Boron	n/a	**1.0105**	n/a	**1.0097**	n/a	n/a	**1.0068**
Misloaded k_{eff} 800 ppm Boron	n/a	**0.9018**	n/a	**0.9103**	n/a	n/a	**0.9156**
Misloaded Conditions Interpolated Boron Concentration to Adjusted k_{eff}	n/a	**668**	n/a	**729**	n/a	n/a	**785**

Note: For the 2.0 wt% U-235 case, the Total k_{eff} 0 ppm Boron value was conservatively increased to 0.9950 for consistency with the other values in the same row.

Table 7.14

Region 2 Results for the Spent Fuel Checkerboard Loading

Enrichment (wt% U235)	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Burnup (GWD/MTU)	3.7	10.7	17.9	24.9	31.5	36.7	43.2
CASMO Burnup for Tolerances	2.0	8.0	15.0	22.5	27.5	32.5	40.0
CASMO Burnup for Depletion Uncertainty	4.0	11.0	20.0	25.0	32.5	37.5	45.0
Depletion Uncertainty	0.0017	0.0051	0.0087	0.0103	0.0126	0.0138	0.0157
Manufacturing Uncertainty	0.0043	0.0043	0.0042	0.0041	0.0041	0.0041	0.0040
Fuel Uncertainty	0.0075	0.0059	0.0051	0.0047	0.0043	0.0040	0.0039
Calculational Uncertainty	0.0012	0.0012	0.0012	0.0010	0.0014	0.0014	0.0012
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total Uncertainty	0.0129	0.0129	0.0144	0.0153	0.0168	0.0177	0.0191
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Temperature Bias	0.0051	0.0041	0.0035	0.0031	0.0029	0.0028	0.0025
IFBA Bias	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070	0.0070
Adjusted k_{eff} (0.995-corrections)	**0.9688**	**0.9698**	**0.9689**	**0.9684**	**0.9670**	**0.9664**	**0.9652**
Adjusted k_{eff} (0.945-corrections)	**0.9188**	n/a	n/a	**0.9184**	n/a	n/a	**0.9152**
MCNP k_{eff} 0 ppm Boron	0.9688	0.9698	0.9689	0.9684	0.9670	0.9664	0.9652
MCNP k_{eff} 600 ppm Boron	0.8868	n/a	n/a	0.8946	n/a	n/a	0.9079
Total k_{eff} without Boron	**0.9950**	**0.9950**	**0.9950**	**0.9950**	**0.9950**	**0.9950**	**0.9950**
Total k_{eff} with 600 ppm Boron	**0.9130**	n/a	n/a	**0.9212**	n/a	n/a	**0.9378**
Normal Conditions Interpolated Boron Concentration to Adjusted k_{eff}	**366**	n/a	n/a	**407**	n/a	n/a	**524**
Mislocated k_{eff} 0 ppm Boron	**1.0075**	n/a	n/a	**1.0059**	n/a	n/a	**1.0056**
Mislocated k_{eff} 600 ppm Boron	**0.9055**	n/a	n/a	**0.9067**	n/a	n/a	**0.9064**
Mislocated Conditions Interpolated Boron Concentration to Adjusted k_{eff}	**522**	n/a	n/a	**529**	n/a	n/a	**547**
Misloaded k_{eff} 0 ppm Boron	**1.0194**	n/a	n/a	**1.0125**	n/a	n/a	**1.0114**
Misloaded k_{eff} 1000 ppm Boron	**0.8973**	n/a	n/a	**0.9011**	n/a	n/a	**0.9007**
Misloaded Conditions Interpolated Boron Concentration to Adjusted k_{eff}	**825**	n/a	n/a	**844**	n/a	n/a	**870**

Shaded areas indicate where proprietary information has been removed.

Table 7.15

Region 2 Results for the Fresh Checkerboard Loading

Enrichment (wt% U235)	5.0
Burnup (GWD/MTU)	0.0
CASMO Burnup for Tolerances	0.0000
Manufacturing Uncertainty	0.0053
Fuel Uncertainty	0.0029
Calculational Uncertainty	0.0014
[redacted]	[redacted]
[redacted]	[redacted]
Total Uncertainty	0.0112
[redacted]	[redacted]
Temperature Bias	0.0034
IFBA Bias	0.0070
MCNP k_{eff} 0 ppm Boron	0.8256
Normal Conditions Total k_{eff} without Boron	**0.8484**
Adjusted k_{eff} (0.945-corrections)	0.9222
Mislocated k_{eff} 0 ppm Boron	1.0171
Mislocated k_{eff} 600 ppm Boron	0.9044
Mislocated Conditions Interpolated Boron Concentration to Adjusted k_{eff}	**505**
Misloaded k_{eff} 0 ppm Boron	1.0151
Misloaded k_{eff} 1000 ppm Boron	0.9050
Normal Conditions Interpolated Boron Concentration to Adjusted k_{eff}	**844**

Table 7.16

Summary of the Criticality Safety Analysis for Region 2, Spent Fuel Uniform Loading, 0 ppm Soluble Boron

Enrichment (wt% ^{235}U)	5.0	
Burnup (GWD/MTU)	34.1	
Soluble Boron ppm	0.0	
Fuel Eccentricity	negative	
Statistical Combination of Uncertainties	±	0.0166
Calculated k_{eff} (MCNP4a)		0.9673
IFBA Bias		0.0070
Bias to 80.33 °F		0.0029
[redacted]		[redacted]
Maximum k_{eff}		**0.9950**
Regulatory Limit k_{eff}		1.0000

Table 7.17

Summary of the Criticality Safety Analysis for Region 2, Spent Fuel Uniform Loading, 448 ppm Soluble Boron

Enrichment (wt% ^{235}U)	5.0		
Burnup (GWD/MTU)	34.1		
Soluble Boron (ppm)	448		
Statistical Combination of Uncertainties		±	0.0166
Calculated k_{eff} (MCNP4a)			0.9173
IFBA Bias			0.0070
Bias to 80.33 °F			0.0029
[redacted]			[redacted]
Maximum k_{eff}			**0.9450**
Regulatory Limit k_{eff}			0.9500

Table 7.18

Summary of the Criticality Safety Analysis for Region 2, Spent Fuel Checkerboard Loading, 0 ppm Soluble Boron

Enrichment (wt% ^{235}U)	5.0	
Burnup (GWD/MTU)	43.2	
Soluble Boron (ppm)	0.0	
Fuel Eccentricity	negative	
Statistical Combination of Uncertainties	±	0.0191
Calculated k_{eff} (MCNP4a)		0.9652
IFBA Bias		0.0070
Bias to 80.33 °F		0.0025
[redacted]		[redacted]
Maximum k_{eff}		**0.9950**
Regulatory Limit k_{eff}		1.0000

Table 7.19

Summary of the Criticality Safety Analysis for Region 2, Spent Fuel Checkerboard Loading, 524 ppm Soluble Boron

Enrichment (wt% ^{235}U)	5.0	
Burnup (GWD/MTU)	43.2	
Soluble Boron (ppm)	524	
Statistical Combination of Uncertainties	±	0.0191
Calculated k_{eff} (MCNP4a)		0.9152
IFBA Bias		0.0070
Bias to 80.33 °F		0.0025
[redacted]		[redacted]
Maximum k_{eff}		**0.9450**
Regulatory Limit k_{eff}		0.9500

Table 7.20

Summary of the Criticality Safety Analysis for Region 2, Fresh Fuel Checkerboard Loading , 0 ppm Soluble Boron

Enrichment (wt% ^{235}U)	5.0		
Burnup (GWD/MTU)	0.0		
Soluble Boron (ppm)	0.0		
Fuel Eccentricity	negative		
Statistical Combination of Uncertainties		±	0.0112
Calculated k_{eff} (MCNP4a)			0.8256
IFBA Bias			0.0070
Bias to 80.33 °F			0.0034
[redacted]			[redacted]
Maximum k_{eff}			**0.8484**
Regulatory Limit k_{eff}			1.0000

Table 7.21

Summary of Region 2 Accident Cases

Case	Result
Dropped Fuel Assembly - Horizontal On Top of Cells	Negligible
Dropped Fuel Assembly - Vertical into Storage Cell	Negligible
Misloaded Fuel Assembly, Spent Fuel Checkerboard Loading, 5.0 wt% ^{235}U (ppm Soluble Boron)	870[6]
Mislocated Fuel Assembly, Spent Fuel Checkerboard Loading, 5.0 wt% ^{235}U (ppm Soluble Boron)	547[7]

[6] This case was the maximum for the misloaded assembly in the spent fuel uniform loading, spent fuel checkerboard loading, or fresh fuel checkerboard.
[7] This case was the maximum for the mislocated assembly in the spent fuel uniform loading, spent fuel checkerboard loading, or fresh fuel checkerboard.

Table 7.22

Region 2 Calculation Results for the Interface Cases

Description		Axial Profile	Enr	Burnup (GWD/MTU)	k_{eff}	Ref k_{eff} (at curve)
Interface between half a rack of fresh fuel checkerboard and half a rack of spent fuel checkerboard	Spent fuel checkerboard loading, fresh FA adjacent 27 GWD/MTU, 5.0 wt% ^{235}U FA	Segmented	2.0	3.7	0.9545	0.9688
		Segmented	3.5	24.9	0.9475	0.9684
		Segmented	5.0	43.2	0.9425	0.9652
		Uniform	2.0	3.7	0.9553	0.9688
		Uniform	3.5	24.9	0.9484	0.9684
		Uniform	5.0	43.2	0.9436	0.9652
Interface between a 3x3 set of fresh checkerboard (fresh in center) surrounded by a rack of spent fuel checkerboard	Spent fuel checkerboard loading, fresh FA adjacent 27 GWD/MTU, 5.0 wt% ^{235}U FA	Segmented	2.0	3.7	0.9684	0.9688
		Segmented	3.5	24.9	0.9625	0.9684
		Segmented	5.0	43.2	0.9570	0.9652
		Uniform	2.0	3.7	0.9688	0.9688
		Uniform	3.5	24.9	0.9659	0.9684
		Uniform	5.0	43.2	0.9597	0.9652
Interface between a set of spent fuel checkerboard loading fuel and spent uniform loading fuel.		Segmented	2.0	3.7	0.9675	0.9688
		Segmented	3.5	24.9	0.9681	0.9684
		Segmented	5.0	43.2	0.9629	0.9652
		Uniform	2.0	3.7	0.9659	0.9688
		Uniform	3.5	24.9	0.9676	0.9684
		Uniform	5.0	43.2	0.9626	0.9652

Table 7.23

Results of the Calculation of the Fuel Transfer Carriage

Description	Calculated k_{eff}
Reference Case	0.9436
Mislocated Case	1.0612
800 ppm Boron Case	0.9209

Table 7.24

Results of the Criticality Analysis for the TSR

Description	Calculated k_{eff}
TSR Design Basis Model	0.9297
TSR Mislocated Fuel Assembly Model	1.0204
TSR Mislocated Fuel Assembly Model with 800 ppm Soluble Boron	0.8525
Extrapolated TSR Soluble Boron Requirement for Mislocated Accident, ppm	359

Table 7.25

Results of the Criticality Analysis for the FPSC

Description	Calculated k_{eff}
FPSC Design Basis Model	0.6715
5.0 wt% ^{235}U Fuel Assembly at 33.4 GWD/MTU	0.7521
5.0 wt% ^{235}U Fuel Assembly at 27 GWD/MTU	0.7784
Fresh NGF Fuel Assembly	0.9226

Table 7.26

Region 2 Burnup Versus Enrichment Curve for Spent Fuel Uniform Loading

Enrichment (wt% ^{235}U)	Burnup (GWD/MTU)
2.0	0.0
2.5	6.4
3.0	12.4
3.5	18.3
4.0	24.3
4.5	28.9
5.0	34.1

Table 7.27

Region 2 Burnup Versus Enrichment Curve for Spent Fuel Checkerboard Loading

Enrichment (wt% ^{235}U)	**Burnup (GWD/MTU)**
2.0	3.7
2.5	10.7
3.0	17.9
3.5	24.9
4.0	31.5
4.5	36.7
5.0	43.2

Table 7.28
Summary of the Criticality Safety Analysis for New Fuel Vault, 100% Moderator Density

Tolerances:					
Enrichment k_{eff}	0.9195	±	0.0008		
Enrichment Uncertainty				±	0.0034
Pellet Density k_{eff}	0.9192	±	0.0008		
Pellet Density Uncertainty				±	0.0031
Storage Rack Pitch k_{eff}	0.9187	±	0.0007		
Storage Rack Pitch Uncertainty				±	0.0023
[redacted]				[redacted]	[redacted]
Calculation Statistics (95%/95%,2xσ)				±	0.0014
Statistical Combination of Uncertainties				±	0.0104
Calculated k_{eff} (MCNP4a)					0.9184
[redacted]					[redacted]
Maximum k_{eff}					**0.9300**
Regulatory Limit k_{eff}					0.9500

Shaded areas indicate where proprietary information has been removed.

Table 7.29

Region 2 Sensitivity Calculations for Depletion Uncertainty with Soluble Boron

ppm	0	[redacted]	
Burnup GWD/MTU	5% Decrement	5% Decrement	Delta ([redacted]-0)
0.0	n/a	n/a	n/a
20.0	0.0076	[redacted]	[redacted]
40.0	0.0141	[redacted]	[redacted]
60.0	0.0201	[redacted]	[redacted]

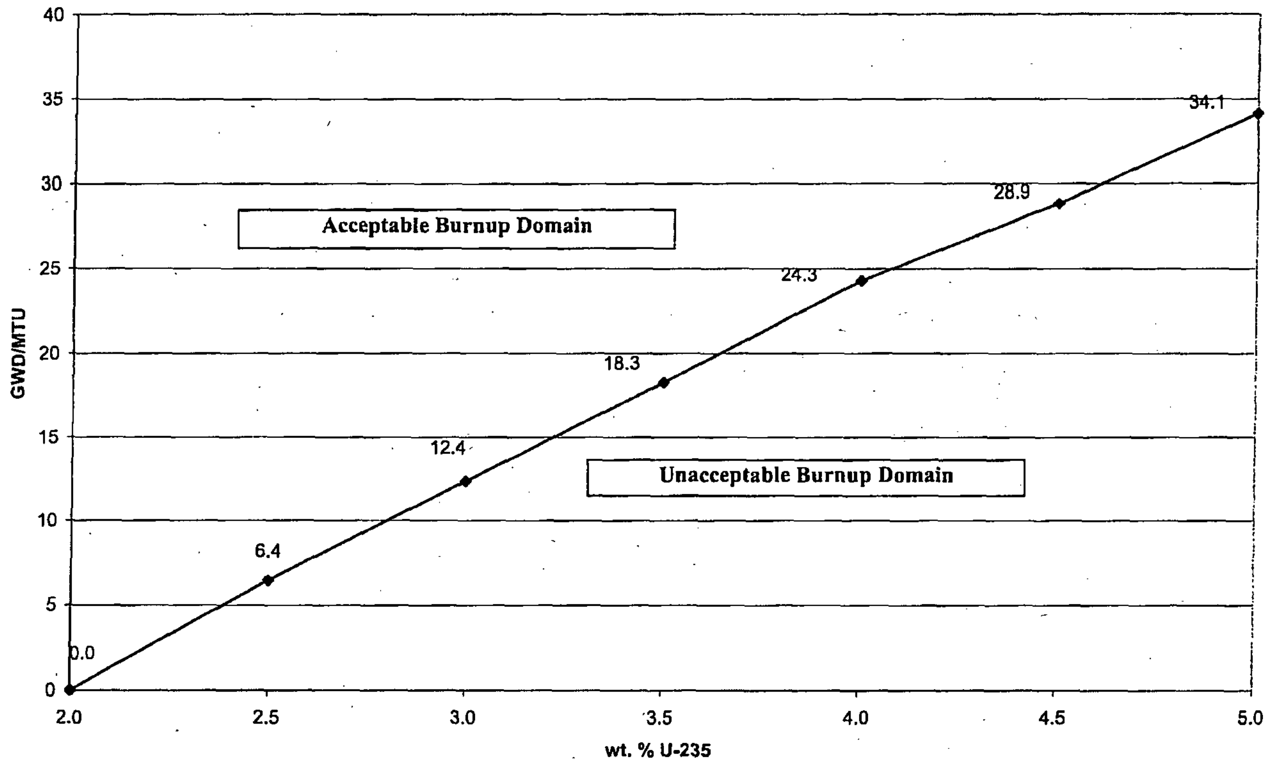
Figure Proprietary

Figure 5.1 Region 1 Model

Figure Proprietary

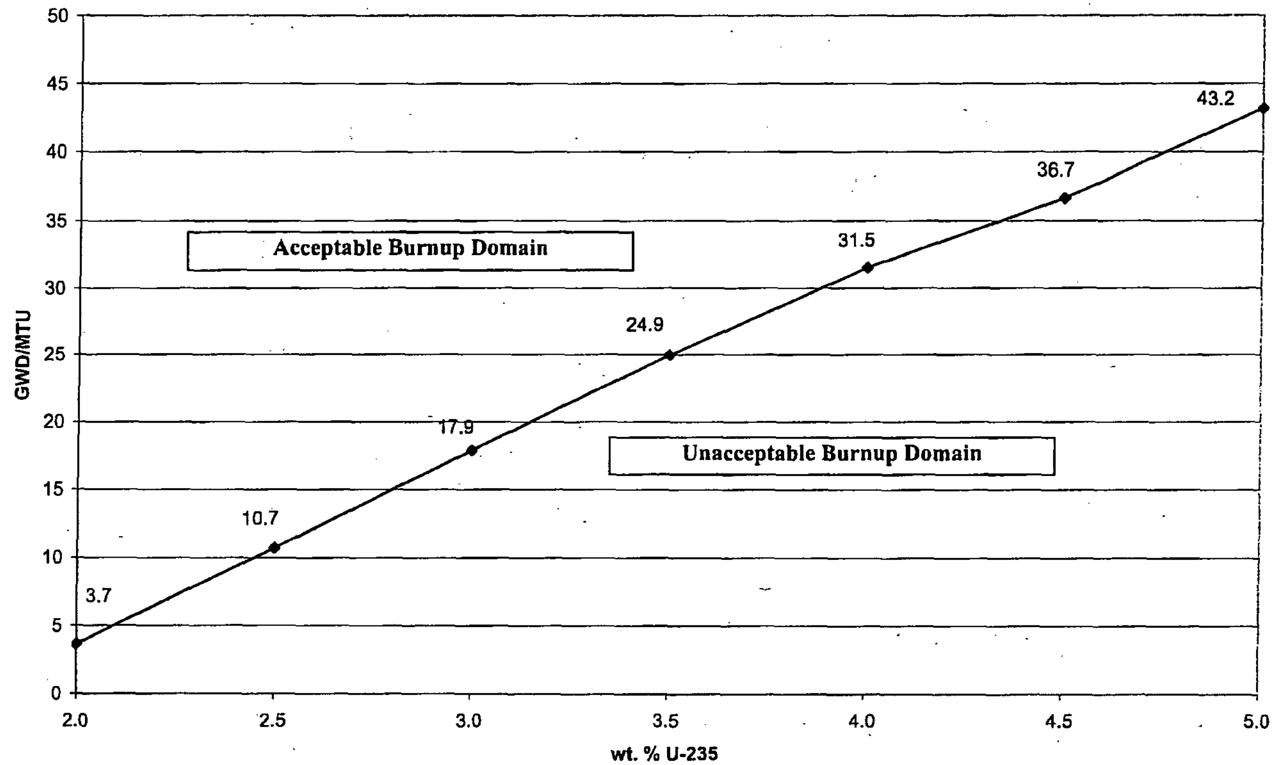
Figure 5.2 Region 2 Model

Figure 7.1
Region 2 Uniform Loading Burnup vs. Enrichment Curve



Note: For Enrichments lower than 2 wt%, apply the burnup value at 2 wt%.

Figure 7.2
Region 2 Checkerboard Loading Burnup vs. Enrichment Curve



Note: For Enrichments lower than 2 wt%, apply the burnup value at 2 wt%.

Figure 7.3
Region 2 intra-rack interface between half a rack of Fresh Fuel checkerboard and half a rack of spent fuel checkerboard

A	B	A	F	E	F	E
B	A	B	E	F	E	F
A	B	A	F	E	F	E
B	A	B	E	F	E	F
A	B	A	F	E	F	E
B	A	B	E	E	E	F
A	B	A	F	E	F	E

A	5 wt% ^{235}U , 27 GWD/MTU
B	Spent Fuel At Spent Fuel Checkerboard Curve
F	5 wt% ^{235}U Fresh or Irradiated Fuel
E	Empty Cell

Figure 7.4
Region 2 intra-rack interface between a 3x3 set of Fresh Fuel checkerboard (fresh in center) surrounded by a rack of spent fuel checkerboard

B	**A**	**B**	**A**	**B**	**A**	**B**
A	**B**	**A**	**B**	**A**	**B**	**A**
B	**A**	**F**	**E**	**F**	**A**	**B**
A	**B**	**E**	**F**	**E**	**B**	**A**
B	**A**	**F**	**E**	**F**	**A**	**B**
A	**B**	**A**	**B**	**A**	**B**	**A**
B	**A**	**B**	**A**	**B**	**A**	**B**

A	5 wt% ^{235}U, 27 GWD/MTU
B	Spent Fuel At Checkerboard Curve
F	5 wt% ^{235}U Fresh or Irradiated Fuel
E	Empty Cell

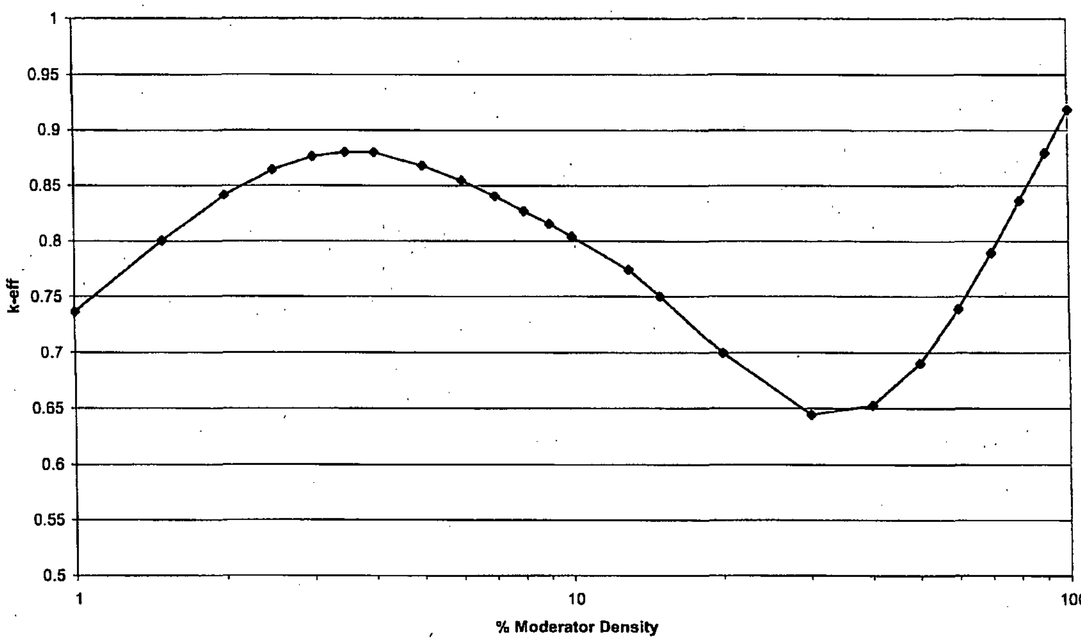
Figure 7.5
Two-Dimensional Representation of the Actual Calculations Model used for the New Fuel Vault as seen from above.

Figure Proprietary

Figure 7.6
Two-Dimensional Representation of the Actual Calculations Model used for the New Fuel Vault as seen from the side.

Figure Proprietary

Figure 7.7
Results of the Waterford Unit 3 New Fuel Vault Criticality Analysis As a Function of Water Density



Shaded areas indicate where proprietary information has been removed.

Appendix A
Benchmark Calculations

HOLTEC PROPRIETARY APPENDIX HAS BEEN REMOVED IN IT'S ENTIRETY